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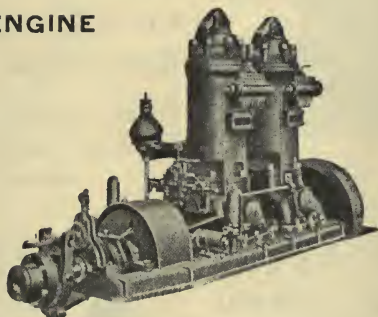
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DOXFORD "YNGAREN" 10,000 TON MOTOR SHIP

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Frontispiece

(1458b)

PITMAN'S COMMON COMMODITIES
AND INDUSTRIES

MOTOR BOATS

A REVIEW OF THE DEVELOPMENT AND
CONSTRUCTION OF MARINE MOTORS
AND MOTOR BOATS, THEIR ADVANTAGES
AND THEIR FUTURE SCOPE

BY
Frederic
F. STRICKLAND
M.I.M.E., M.I.A.E.



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24-7.24

LONDON
SIR ISAAC PITMAN & SONS, LTD.
PARKER STREET, KINGSWAY, W.C.2
BATH, MELBOURNE, TORONTO, NEW YORK



PRINTED IN GREAT BRITAIN
AT THE PITMAN PRESS, BATH

PREFACE

THE most striking development of modern times is undoubtedly the development of the motor car on the road. While it is possible that there might have been an extension of mechanical traction with steam as a motive power on a small scale, there is no doubt that the essential reason for the enormous extension which has taken place is the great improvement in the internal combustion motor, which has put into the hands of the user a very much simpler and lighter form of motive power than the steam engine, and one which is cheaper to build.

As steam was already in use for marine work, the development of the internal combustion engine here has been slower than on the road, and, further, there have been some special difficulties to overcome. Nevertheless, it is quite possible that the marine motor may one day be quite as important as the road motor. I have therefore endeavoured in this volume to explain, in non-technical language, the principles on which the marine motor works and the variation in requirements and working, at the same time showing its advantages over the steam engine and its possible scope. My thanks are due to the various firms who have kindly furnished me with information and illustrations.

CONTENTS

	PAGE
PREFACE	v
CHAPTER I	
DEFINITION of motor boats—History of the motor boat—Development of the marine engine from the stationary oil engine on the one hand, and from the motor car engine on the other—Influence of racing—Motor boats in the war	1
CHAPTER II	
ACTION of the internal combustion motor—Four-stroke engines—Two-stroke engines—Difference in action between steam and internal combustion engines—Different ways of mixing the fuel and the air . . .	11
CHAPTER III	
COMPARATIVE merits of the four-stroke and two-stroke, and of the gas mixture type and the injection type . .	32
CHAPTER IV	
ADVANTAGES of motor boats—Defects of steam engines—Advantages of motors in fuel economy, lower weight and less space occupied—Economy in labour—Possibilities of higher speeds than with steam—Possibility of making marine motors of smaller size than is practicable with steam machinery	37
CHAPTER V	
FUELS for motor boats—Petrol—Paraffin—Fuel oil—Advantages and disadvantages of each	45
CHAPTER VI	
ENGINE speed, power, and weight—Light weight per horse-power dependent of high engine speed—Objections to very high engine speed—Need for compromise and moderation	56

CHAPTER VII

PAGE

How a high speed boat skims—Essential differences between the skimming boat and the ordinary boat— Objections to some forms of skimming boats— Possible compromises	62
--	----

CHAPTER VIII

EXAMPLES of motor boats in practice—Evinrude, Thornycroft, Brooke, Sterling, Vickers Petter, Doxford .	68
--	----

CHAPTER IX

SCOPE and further possibilities of motor boats in the future—Present limits of size—Probable increase— Very great increase in the sizes possible in the last few years—Advantages for large ships—Great possi- bilities in the case of the smaller sizes—Probable effect of the motor boat quite revolutionary . . .	102
INDEX	115

ILLUSTRATIONS

FIG.		PAGE
	DOXFORD "YNGAREN" 10,000 TON MOTORSHIP	
	<i>Frontispiece</i>	
1.	FOUR-STROKE ENGINE, SUCTION STROKE . . .	13
2.	FOUR-STROKE ENGINE, COMPRESSION STROKE . . .	15
3.	FOUR-STROKE ENGINE, EXPLOSION STROKE . . .	17
4.	FOUR-STROKE ENGINE, EXHAUST STROKE . . .	19
5.	TWO-STROKE ENGINE, SUCTION . . .	21
6.	TWO-STROKE ENGINE, CHARGING . . .	23
7.	REVERSING GEAR	30
8.	CARBURETTOR, SECTION OF	49
9.	SKIMMING BOAT AT REST.	66
10.	SKIMMING BOAT RUNNING	66
11.	EVINRUDE RUDDER MOTOR	71
12.	EVINRUDE RUDDER MOTOR, BOAT FITTED WITH . . .	75
13.	THORNYCROFT COASTAL MOTOR BOAT	77
14.	THORNYCROFT 18 H.P. TWO-CYLINDER ENGINE . . .	79
15.	THORNYCROFT 35 FT. CRUISER	81
16.	BROOKE 40 FT. TUG BOAT	83
17.	BROOKE 30 FT. CRUISER	85
18.	BROOKE 30 FT. CRUISER CABIN	86
19.	STERLING 45 FT. CRUISER	87
20.	STERLING 66 FT. CRUISER	89
21.	STERLING 300 H.P. ENGINE	90
22.	VICKERS-PETTER, SECTION OF ENGINE	91
23.	VICKERS-PETTER 500 H.P. SIX-CYLINDER ENGINE . .	93
24.	VICKERS-PETTER AUXILIARY 2,000 TON SHIP . . .	94
25.	GREI 70 H.P. TWO-CYLINDER ENGINE	95
26.	DOXFORD 2,700 H.P. ENGINE	99

MOTOR BOATS

CHAPTER I

DEFINITION AND HISTORY

What is a "Motor Boat"? The word "motor" has come into use to mean various things. Thus, there are electric motors, water motors, etc.

To most people, however, the word "motor" is associated with a motor car, which is usually propelled by a petrol engine. Some motor cars are, however, propelled by steam and some by electricity. Steam has, however, been in use for propelling ships for a very long time, so obviously steam boats are out of the scope of a book on motor boats. In fact the word "motor boat" came into use from the fact that many of the earlier engines used in boats were petrol engines of essentially the same construction as used on motor cars.

Now the essential difference between the steam engine, which has been in use for all purposes for a very long time, and the petrol engine is that in the steam engine the fuel is burnt under a boiler and the steam made used in an engine, while in the petrol engine the fuel is burnt in the cylinder of the engine itself. This is the principle on which all gas and oil engines work, and was used first in gas engines. Owing to the fact that the fuel is burnt inside the cylinder itself such engines are called by engineers "Internal Combustion engines." This title is commonly shortened to "I.C." engines.

Although many of the modern engines of this type differ very widely from the petrol engine as used in a car, especially in the larger sizes, the engine developed from the motor car engine grades off into the large marine oil engine so gradually that no actual dividing line can be drawn. Accordingly, for the purposes of this book, all ships propelled by "I.C." engines will be considered as motor boats, from the light rowing boat fitted with a 2 horse-power motor, to the large ship carrying 10,000 tons. The action of the I.C. engine, and the way it differs from the steam engine, will be described in the next chapter.

As is well known, steam has been used for propelling ships for more than 100 years. Previously to that it had been used on land, first for pumping, then for other purposes. Weight is of little importance in a stationary engine, but it is very important in a ship, and the development of the marine steam engine has been constantly in the direction of less weight for the power developed and also less coal burnt. In spite of the economies effected, however, the amount of coal burnt by a large steamer is very great, in some cases about 1,000 tons a day. Accordingly a large number of stokers have to be carried.

In order to save labour and reduce the space taken by the fuel a considerable number of steamers have been fitted to burn oil in the boilers. This has many advantages, but there is no doubt that if oil is used at all it should, if possible, be used in an I.C. engine for the simple reason that such an engine uses far less oil for a given power than a steam engine.

While steam has undoubtedly been very satisfactory in large ships there are distinct limits to its use in small boats. It is difficult to make a steam engine small enough and light enough for many purposes, and when

in use it requires a good deal of attention. Accordingly, before the advent of the petrol motor a very large number of boats were in use for fishing, coasting, etc., which were propelled only by sails or oars.

We must now turn to the history of the internal combustion engine.

These first began to come into general use about 1880 as stationary engines, using ordinary town gas. The main advantages were that they required practically no attention while running, and could be started at once without getting up steam, as is necessary in a steam engine. This led to their being used very largely for small powers. Later such engines were made to use oil.

Being made for stationary work no attempt was made to make them light, but some small marine engines on the same principle, using oil, were made commercially about 1890, and the trade in them steadily developed, though only on a small scale. Gradually, however, improved methods of using the oil came into use, and there is no doubt that the large engine used in the big cargo motor boats developed essentially from the stationary oil engine.

Meanwhile, perhaps the most important development of modern times, namely, the use of the petrol engine, was taking place. The petrol engine is a gas engine using gas made from petrol, which is a very volatile spirit. The use of such engines on road vehicles caused a type to be developed entirely different from anything which had preceded it. It is, in the first place, necessary that the engine in a motor car should be far lighter than any of the engines in previous use, and also that it should run for a long time without any attention other than supplying it with petrol and lubricating oil.

Progress will be seen if we take the weights per horse-power. The lightest steam engines in practical use were those in torpedo boats, which weighed from 40 to 50 lb. for each horse-power developed. These were, however, only fit to be put in the hands of very skilled men, and ordinary steam launch machinery weighed over 100 lb. per horse-power. Competition in the motor cars very soon produced petrol motors weighing under 10 lb. per horse-power, and they required practically no skilled attention.

Naturally, such engines were used in boats, and it was soon found that quite unheard of speeds could be obtained owing to their great power in proportion to their weight. A great landmark was the race for motor boats from Calais to Dover in 1904, when a 40 ft. boat, fitted with a 60 h.p. Mercedes motor, covered the 22 knots in an hour. This was a speed far higher than had been obtained by any boat of the size before, and incidentally the steamer which had been chartered to follow the race was ignominiously left behind, although she was one of the fastest of the cross channel boats.

From then the progress of the high-speed boat has been rapid. It was found that the motor car engine was not the most suitable one for a boat, and special petrol motors were made for marine work. There are three great differences between the car and the boat which affect the engine—

Firstly, a marine motor has to work at its full power for a long time without any easing down. This is quite different from the work of a motor in a car where the throttle is never full open for more than a minute or two at a time and is often nearly shut. A second difference is that in a powerful car the engine always has a strong draught of air round it when it is going fast, and this helps to cool it. For these reasons it was found

necessary to fit engines with far larger bearings for a given power in a boat than were necessary in a car, and also to have improved lubrication systems.

A third great difference is that in a car it is quite easy to get at the engine from below, and engines are usually designed so that the bearings are accessible in this manner. In a boat, of course, this is impossible, and the engine must be designed so that they can be adjusted from above. There are other minor points.

For these reasons it was soon found that it was not satisfactory to simply take an existing car engine and put it into a boat. Hence specially-designed petrol engines, made on the lines of the car engine but modified, began to make their appearance and were soon made of powers far greater than are usual in a car. Many of these are made by firms who have previously made small marine steam engines.

With such engines the increase of speed has been very great. For purely racing purposes over 800 h.p. has been put into a 26 ft. boat, and a speed of 77 miles an hour or 66 knots has been got. Such boats are, of course, purely racing machines of no practical use, but their development has helped that of more useful types. Thus there were boats used in the war 55 ft. long, capable of a speed of 40 knots and also capable of going to sea in fairly rough weather. That is to say, they were practically twice as fast as the racing boat of 1904, and in place of being useless racing machines were seaworthy craft, capable of carrying considerable armament. These will be described in detail later.

Really high-speed boats have only a very limited application as they are very expensive to build; their machinery is very delicate and also their petrol consumption enormous.

The development of the high-speed boat, however,

caused motors to be reduced in weight and size for a given power, and this has been of benefit in the slower boats. Thus, if we want a motor boat only to go the speed of the older steam boats we can put the needful power into her with far less weight and space taken up. Further, without taking up the space of the old steam machinery, a petrol engine will propel a boat at a speed higher than was ever practicable for steam.

A further advantage of the petrol engine is that fuel can be carried for longer distances without filling up. Then, again, the petrol engine can in practice be made of smaller sizes than is satisfactory with steam. Hence it can be used for boats so small that steam is impracticable.

The natural consequences of these advantages are, firstly, that the petrol motor has very largely superseded steam for small craft, secondly, that the petrol motor is being used for a great many purposes for which steam was impracticable, and therefore is finding an additional field of its own.

In fact the advent of the petrol motor has caused a very great increase in the use of power for the smaller sizes of boats, and very soon sails and oars are likely to be almost extinct except as a means of pleasure. The manufacture of marine motors will soon take its place as one of the large manufacturing industries of the world. So far this development has been far greater in the U.S.A. than in Europe. The reasons for this are partly in the natural advantages of the country and partly from the nature of their fiscal policy. The U.S.A. has a very long coast line and a climate very well suited for pleasure cruising, while it has a very large and wealthy population.

There is, therefore, a very large market for petrol motor boats, and this market is secured to the home

producer by a heavy import duty. Naturally this has resulted in manufacturers producing on a scale which it would be quite unwise for any manufacturer to do here, and the consequence of the large output is that motors can be produced very cheaply. It must always be remembered that the cost of an article is mainly governed by the number produced; the greater the number the less the cost. Hence, makers who have a very large and secure market can manufacture in greater quantities than those who are not so situated, and therefore at a cheaper price. This naturally gives them an advantage in export trade.

In the U.S.A., as here, the development of the petrol motor for pleasure purposes has been followed by its very large use for various kinds of business purposes.

There are two great objections to petrol as a fuel for boats, especially in the larger sizes, namely, expense and danger. Accordingly many engines essentially of the type of the petrol engine are actually made to burn ordinary paraffin.

We see, therefore, that the marine motor has started from two quite different points. On the one hand, there was the modification of the stationary engine which was enormously heavy but which is very economical, uses the cheaper form of oil, and is intended to last practically for ever. This was lightened and used for the slower classes of boats which only carry cargo and therefore only want low powers in proportion to their weight. This has displaced steam for many types of boat on account of its lower fuel consumption, smaller space taken up, and generally more economical working costs. It is mainly from this type that the really large engines used in cargo ships have been derived.

On the other hand, there is the type which was derived from the petrol engine as used in the motor car. This

was modified for use in the motor boat, and generally made considerably more substantial. It was also often made to burn paraffin.

Gradually, with experience, intermediate types between these two have been constructed, and in fact the two types have a strong tendency to come closer together.

The result is that the marine motor is becoming a distinct production, different from either the car motor or the stationary engine, and is made almost entirely by marine engine builders, and since this has been the case its use has extended enormously for all classes of work, from the smallest 2 h.p. motor, which can be attached to a rowing boat, to the largest sizes which it is at present practicable to make of some thousands of horse-power. It is difficult to say whether the small or the large engines have had the most important effect in the history of mechanical progress. Naturally, if we take the case of a single engine, an engine of some thousands of horse-power is of more importance than one of only a few horse-power. On the other hand the small engines are made in such large numbers that the total output in horse-power of a maker of small engines may be greater than that of the maker of large ones.

The Motor Boat in War. A very important part of the history of the motor boat is its development as a fighting machine and the effect of its use in the late war.

In this connection it must be remembered that the submarine is essentially a motor boat. It is true that a few submarines have been built with steam engines, but the great majority use oil motors essentially of the same type as were developed for the ordinary motor boat, and it is improbable that the submarine would have been developed before the war to any really important extent if such motors had not been available.

In any case without the I.C. engine the long cruises of the German submarines would have been impracticable, and therefore their effect on the war would have been small.

It is hardly necessary here to point out what an enormous effect the submarine had on the course of the war. Without it the Germans would have been unable to materially affect our shipping and the whole course of events would have been different.

While the marine motor gave the Germans a very powerful weapon against us it also gave us weapons to use against him, and especially against his submarines. Not only did we also use submarines but we used surface motor boats in very large numbers, and it was largely the constant patrolling by these boats that limited the powers of the German submarines.

Many of these motor boats were simply existing pleasure cruisers, lent or commandeered. The large majority were, however, specially built.

They were mainly of two classes. The "M.L.s" were boats about 80 ft. long, 400 h.p., with a speed of some 19 knots. These boats were, in fact, about the same length, power, and speed as the very early sea-going steam torpedo boats of some forty years ago. As compared with such steam boats their great advantages were—

First, the machinery takes up much less room, and therefore leaves more accommodation for the crew.

Second, the machinery require much less attention when running.

Thirdly, they can carry fuel for very much greater distances without refilling.

The second type were the "Coastal Motor Boats." These were mainly 55 ft. long, about 800 h.p., and 40 knots speed. They were, in fact, about the same size

as the very earliest torpedo boats but well over double the speed.

It has always been recognized that there are great advantages in having torpedo craft small, but it is absolutely necessary for them to be very fast. With steam it is impossible to get the speed now required without making the boats very large, with the result that the small steam torpedo boat has grown into the "destroyer," in which to get a speed of 40 knots the boat has to be made some 300 ft. long, and about 30,000 h.p. Even with the most modern steam machinery it would be impossible to get a speed on service above about 20 knots in a boat 55 ft. long. With the petrol motor, however, we can combine the speed of the large destroyer with the advantages of very small size, namely, small target, small draught of water, low cost, and small crew.

These advantages of the motor enabled it to be built and used in numbers which would have been quite impracticable in the case of steam vessels.

Considering the enormous effect of the submarine campaign and the anti-submarine campaign on the war, there is no doubt that the motor boat was one of the principal factors on both the course it took and its result.

CHAPTER II

ACTION OF THE INTERNAL COMBUSTION MOTOR

WE have seen that the definition of a motor boat, as distinct from those propelled by steam, electricity, or anything else is that they are driven by "Internal Combustion" motors. What, then, is an internal combustion motor?

An internal combustion motor is one in which the fuel is burnt inside the working cylinder under pressure in place of being burnt outside the vessel containing the working fluid. The ordinary steam engine is of the latter class, and its action is too familiar to need detailed description. In it water is pumped into a boiler and coal or other fuel is burnt under the boiler. The water is thus made into steam under pressure, and this is admitted into each end of a cylinder alternately by suitable valves and by pushing the piston backwards and forwards turns the crank shaft and wheels,

The internal combustion engine works on a radically different principle, for the fuel is burnt actually in the cylinder itself. There are two distinct forms of this type of engine in common use, the one in which the fuel, whether oil or coal, is made into gas and mixed with the air before being taken into the cylinder, and the other in which air alone is taken into the cylinder and the fuel is sprayed into it afterwards. The first type is at present far the most common, and we will therefore take its action first.

The ordinary cycle of this engine is known as the "Otto" or "four stroke" cycle, because it was

first brought into use by a man called Otto and because it takes four strokes to complete the cycle. The action of this will be seen from Figs. 1 to 4. A charge of gas and air is drawn into the cylinder through a suitable valve (A), called the "inlet valve" (Fig. 1). On the piston getting to the end of the stroke the valve shuts and the piston then returns and compresses the charge into the space at the end of the cylinder called the "compression space" (Fig. 2). When the piston has reached the top of this stroke, called the "compression stroke," the charge of gas and air is fired by an electric spark or other means and "explodes." That is to say, the gas burns in a very small space of time and the heat from this raises the pressure a great deal. This high pressure drives out the piston (Fig. 3). At the bottom of the stroke the exhaust valve (B) opens, and when the piston returns the waste gas is driven out (Fig. 4). The exhaust valve then shuts and the inlet valve opens, and the cycle recommences, a fresh charge of gas and air being drawn in as in Fig. 1. The valves are moved by means of suitable gears and cams.

Although the burning of the gas in the cylinder is commonly called an "explosion," it is very important to realize that it is something very different from an explosion of, let us say, dynamite. All explosion is only very rapid combustion, and it is impossible to say at what particular rate of combustion it ceases to be "explosion" and becomes regular combustion. High explosives, such as are used for bursting shells, explode practically instantaneously. Their action is so instantaneous that they cannot even be used to propel the shot from a gun as they would burst the gun before the shot had time to start. Hence the powder used in a gun is made to burn very much slower, the rate being slower the larger the gun. Yet to the eye the explosion

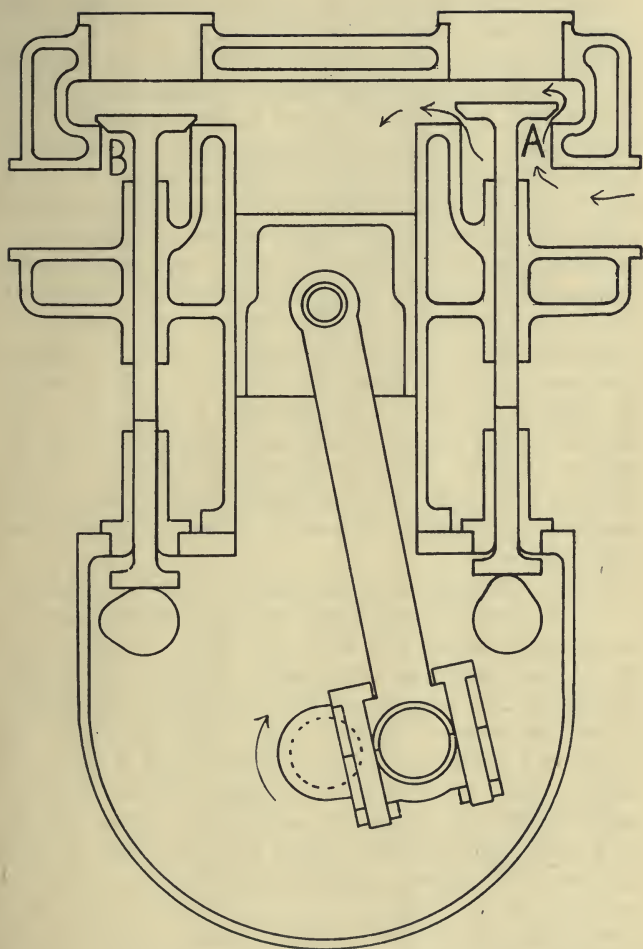


FIG. 1

of the charge of even the largest gun seems quite instantaneous.

The explosion of the charge in the cylinder of a gas engine is again something far less violent than that of the charge of even the slowest burning powder in the largest gun. It can, to a very large extent, be regulated by the amount the charge is compressed before being fired, and other points within the control of the designer.

We see the relative violence of these "explosions" from the pressures obtained. With a gun the pressure before the shot really starts varies from about 4,000 lb. per sq. in. in the case of the ordinary shot gun to ten times this in the high velocity rifle. In the I.C. motor the pressure very seldom exceeds 600 lb. at the moment of explosion, and is very generally a great deal less. 300 lb. to 400 lb. per sq. in. is a very fairly high explosion pressure for a moderate-sized motor. When running throttled, as a car engine generally does, the maximum pressure is, of course, a very great deal less than this.

It is very important to recognize that the "explosion" in an I.C. motor is something quite different from what is generally understood when we talk of "explosions," for a great deal has been said as to the impossibility of making such engines run smoothly like steam engines on account of the "blows" due to the explosions. As a matter of fact, some steam engines work at pressures higher than the explosion pressure of the ordinary petrol engine, and the steam can be let into the cylinder of a steam engine quick enough to cause quite as great a blow to the piston as the explosion of the charge of gas and air.

When the gas and air explode the air is heated to the equivalent of a white heat, and this is in the cylinder for two strokes out of every four. Naturally, therefore,

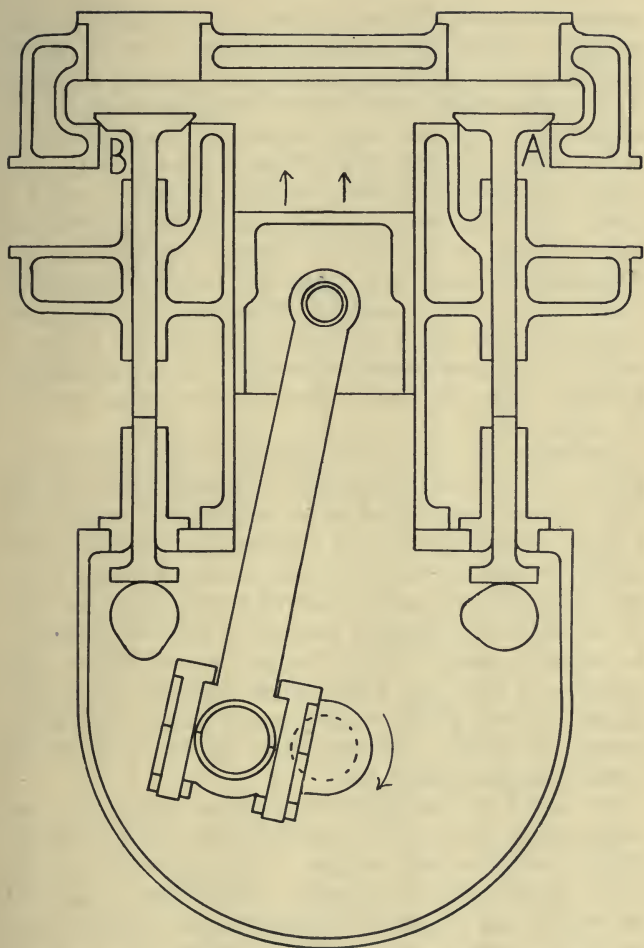


FIG. 2

unless means were taken to cool it the cylinder would soon get red-hot and the engine would cease to work. Accordingly the cylinder is made with a jacket all round it through which water is continuously circulated to keep it cool. In some small motor cycle engines there is no water jacket as the cylinders have ribs cast on them, and the wind blowing on these keeps the cylinder fairly cool. In Aero engines also there is often no water jacket, as the speed through the air is some 100 miles an hour or more, and this keeps the cylinders cool enough. The reason for dispensing with the water cooling in these cases is to avoid carrying the radiator, which is necessary to cool the water. In marine motors, however, water is always used for cooling as there is an ample supply.

Naturally the top of the piston is just as liable to get hot as the rest of the cylinder. In engines of moderate size, however, no special means are taken to cool it as a great deal of the piston touches the cylinder walls, and it is found that the heat is conducted away from the centre part enough to keep it from getting too hot. In the really large engines, however, it is found necessary to circulate water through the pistons, which are cast hollow and have the water taken to them by flexible pipes. Pistons which are not water-cooled are always made a loose fit in the cylinder at the top to allow for their expansion with heat.

We see from the above description that there are several very important points in which the I.C. engine differs from the steam engine. One of these is that the steam engine can start itself. The steam is made in the boiler, and it takes a certain amount of time to get up steam. When it is got up, however, we have a reservoir of steam under pressure which we can turn into the cylinder and the pressure on the piston then

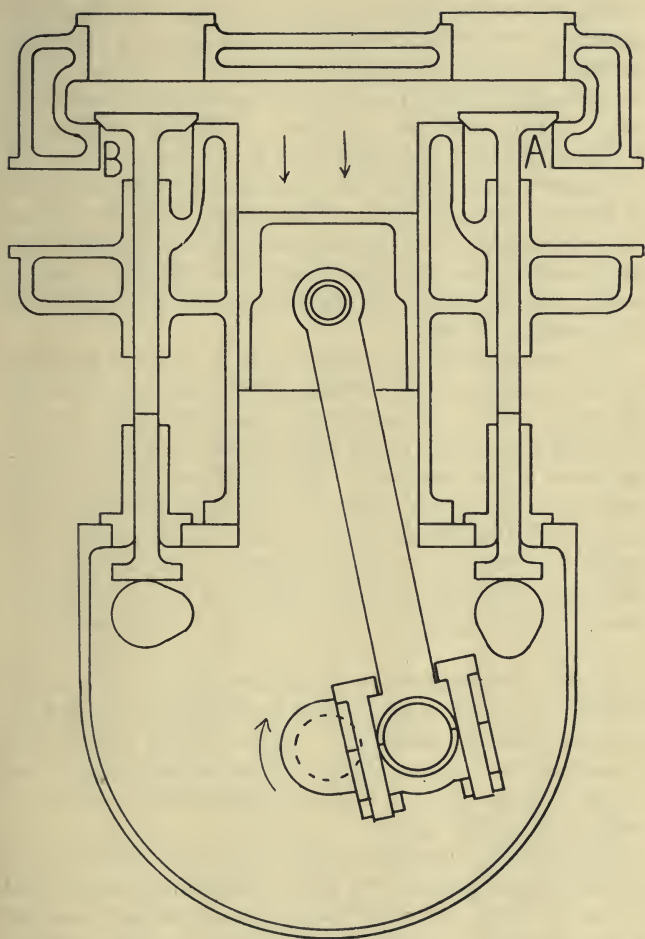


FIG. 3

makes the engine start. It is, of course, necessary to have two or more cylinders in a steam engine to be quite certain of starting, but the principle is evident. We see this actually take place every time we see a locomotive start a train out of a station. The I.C. engine, as described, cannot start itself, as it is necessary to draw a charge of gas and air into the cylinder and compress it before it can be fired. This means that the engine must be driven one complete revolution before it can drive itself. We are again quite familiar with this by seeing the ordinary taxi driver start up his engine by the starting handle.

The action of the I.C. engine is, in fact, rather like that of the treadle in the ordinary foot lathe. When the lathe is at rest we cannot start by pressure on the treadle but pull the crank round with the belt. The action is the same in another way. The treadle of the lathe only drives intermittently and on the upstroke the treadle has to be lifted by the momentum of the flywheel. So in the I.C. engine, as described above, there is only one working stroke out of every four, and the engine must have a heavy flywheel to carry it over the other three strokes.

In the smaller-sized engines starting is quite easily effected by turning the engine by hand, but even here it is not always convenient. In the larger engines this is impossible. Accordingly various arrangements are in use for starting the engines mechanically, and these will be described later.

The fact that the engine only has one impulse for every two revolutions is no very great disadvantage in certain classes of work, as a heavy flywheel can be used to make it run steadily, but this entails extra weight. Hence it is usual to make engines with several cylinders so that the impulses may be more continuous. The

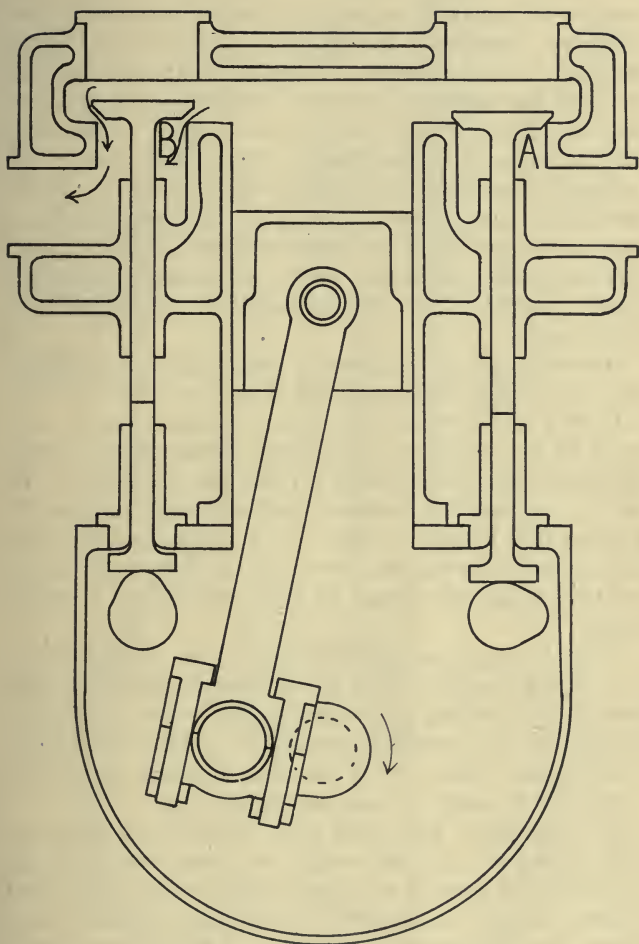


FIG. 4

number of cylinders, accordingly, varies very greatly for different purposes. In marine motors the actual number in common use is usually anything from one to eight for different purposes. For the very smallest sizes the single cylinder is common owing to the need for cheapness and simplicity. For general use in all ordinary sizes from, say, 20 h.p. up to 2,000 or 3,000, the four or six cylinder appears far the most used. A considerable number of eight-cylindere engines are, however, made, while for special purposes engines with twelve, eighteen, or even twenty-four cylinders have been used.

Naturally, the more cylinders the steadier the running, but the greater the complication and expense.

It may be observed here that in a steam engine it is usual to use steam on both sides of the piston, hence the piston has two working strokes per revolution. In an I.C. engine, for various practical considerations, it is usual only to use one side. As a result we must have four cylinders on the above cycle to get the same number of strokes per revolution as one cylinder of a steam engine.

In order to get over the difficulty of the small number of working strokes in the above cycle another one has been devised which gives an impulse every revolution instead of each alternate revolution. This is called the "two-stroke cycle" as it has one working stroke for every two strokes, i.e. one down, one up.

In its simplest form this type of engine is shown in Figs. 5 and 6. In this engine the crank case is made air tight, and there is an exhaust port on the side of the cylinder which is uncovered by the piston a little way before the bottom of the stroke. A little lower down there is another port, which is uncovered by the piston slightly later in the stroke, which communicates with

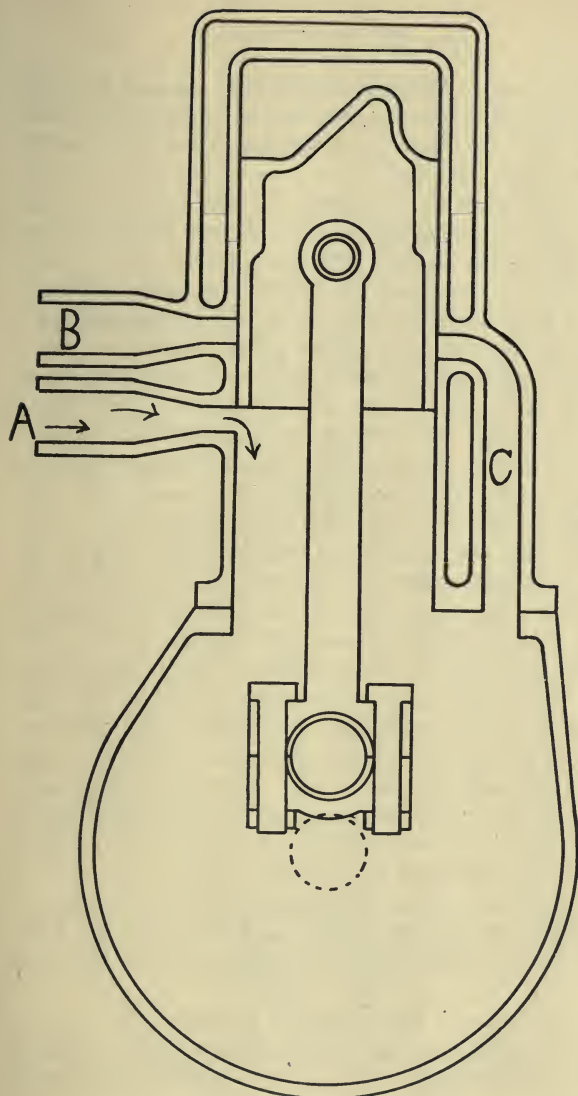


FIG. 5

the crank case. There is also a port leading into the crank case which is uncovered by the skirt of the piston at the top of the stroke, and this forms the inlet for the mixture of gas and air.

Let us start with the piston at the bottom of the stroke, and the cylinder full of a mixture of gas and air from the action of the previous stroke. The piston goes up and compresses the mixture in the usual way. When it gets nearly to the top of the stroke the inlet port (A) is uncovered. As the piston went up it made a slight vacuum in the crank case and, therefore, when this port is uncovered, air and gas rush in and fill the crank case (Fig. 5). The charge is now fired and the piston is driven down. This slightly compresses the charge in the crank case. When the piston gets near the bottom of the stroke the exhaust port (B) is uncovered and the burnt gas rushes out. When the piston gets still nearer the bottom of the stroke the port (C) is uncovered (Fig. 6). As the gas in the crank case is under a slight pressure it rushes up into the cylinder and pushes the remainder of the burnt gas out of the exhaust port. The piston has, on the top, a deflector (D) so shaped that the fresh charge is thrown up to the top of the cylinder and does not mix to any great extent with the burnt gas. The volume of charge drawn into the crank case is slightly less than the volume of the cylinder, so theoretically none of the fresh charge should go out through the exhaust port.

We have here a great division between two classes of engines, the one the two-stroke and the other the four-stroke. The relative merits of these will be discussed later.

We now come to another great division.

In both the above engines it is assumed that the fuel is in the form of gas. This does not mean necessarily

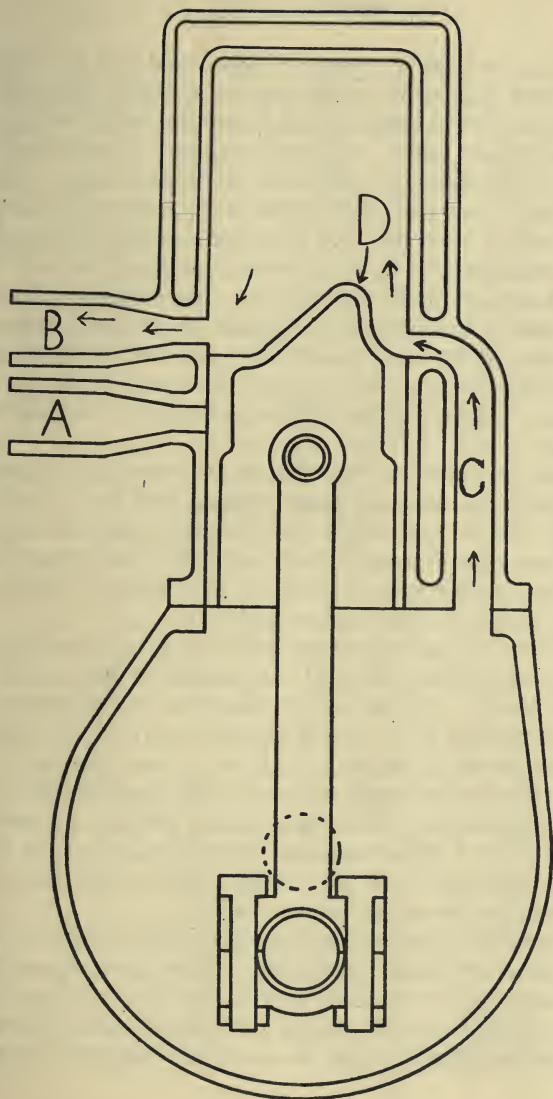


FIG. 6

coal gas, and, as a matter of fact, coal gas is hardly ever used in marine work. Oil or spirit of some kind is almost always used, but it is usually made into gas before being taken into the engine. Theoretically, there is no reason why the fuel should be always made into gas. Any fuel divided finely enough will explode when mixed with air, and very serious explosions take place occasionally in coal mines and flour mills from coal dust and flour respectively. Very finely-sprayed oil should, theoretically, explode also. In practice, however, all fuels, if mixed with the air before being taken into the cylinder, are made into gas of some form or other. Details of this will be given under the heading of fuels.

Oil is, however, now used a great deal without being made into gas first, by being sprayed into the cylinder, at the end of the compression stroke, after air alone has been compressed. There are two types of engine working in this manner, called the "Diesel" and the "hot bulb" engines respectively.

In order to understand the action of these, it is necessary to study the action of the ordinary engine a little more closely. We have seen that the usual arrangement is to draw a mixture of gas and air into the cylinder and compress it before it is fired. Now, gas and air will explode quite well without being compressed, and the compression of the charge takes power. It would appear at first sight that there would be no gain in the compression, as when the charge fired we should only get back the power we had put in.

In practice, however, we find that if we compress the charge before firing it we gain a good deal of power, even allowing for the power used for the compression. The earliest practical gas engines did not compress the charge but simply drew in a certain amount, which

was fired without compression. It is found, however, in practice that if the charge is compressed before it is fired a great deal more power is got, and the consumption of gas is very much smaller. The modern engines using compression only use from a quarter to a third of the gas per horse-power which was used by the old engines without compression.

Naturally, one would think that if compression was such a good thing one could not have too much of it, and that the more the charge was compressed the less fuel would be burnt per horse-power. This is so up to a certain point, but there are limits to the compression which are useful. In practice, engines taking in the fuel with the air usually compress the charge to somewhere about a fourth or a fifth of its original volume. In other words, the compression pressure is about from 80 to 120 lb. per sq. in.

Among the various practical limits to the useful compression pressure, there is only one which need concern us here. That is what is called "pre-ignition."

When any gas is compressed it gets hotter. Also when the mixture of gas and air is compressed the ignition point gets lower, that is to say, that the charge will fire at a lower temperature. Theoretically, therefore, it should be possible to make an engine which would work with no special means of ignition, the compression pressure being so arranged that the gas would fire just at the top of the compression stroke. In practice, however, this is not satisfactory for many reasons. In the first place, although the cylinder of the engine is kept cool by a water jacket, still the inside of the cylinder is often more or less coated with soot, etc., and there are often hot particles in it. As these vary from time to time, it means that sometimes the engine would fire at the right time just at the top of the stroke, and

at other times a long way before the top. In practice, also, a charge which is too highly compressed explodes too violently to make a satisfactory engine, even though the compression pressure is not enough to make it explode spontaneously. This makes engines "knock," and the more carbon or soot there is in the cylinder the more they do it. For these and other reasons it is found best to limit the compression pressure to something a considerable way below that at which the charge would ignite spontaneously.

Where oil is used as a fuel, however, there is an alternative method of using a very high compression, and that was adopted by Dr. Diesel. In his engine the oil was not gasified and mixed with the air before the latter was taken into the cylinder, but pure air was taken in and compressed alone. The compression space was made very small and the air compressed to about 500 lb. per sq. in. This made it practically red-hot. The oil was then sprayed into the red-hot air in a very fine spray by means of compressed air, at a higher pressure than the air compressed in the cylinder. As the oil met the red-hot air it took fire and burnt.

We have here a means of employing a very high compression indeed, and there can be no fear of pre-ignition as the oil is not mixed with the air on the compression stroke, and obviously there can be no combustion till there is some oil to fire. There is no danger of the explosion being too rapid and violent as it takes some perceptible time for the oil to be sprayed in, and we can make this time as long as we like. Owing to the high compression the economy is very good indeed. Further, we can get the advantage of this high compression when the engine is not working at full power. When the gas and air are mixed before going into the cylinder, it is necessary to have the

mixture of fuel and air pretty exactly of one proportion, or else it will not explode. Hence, if we want to work at half power both the air and fuel have to be throttled. This means that the compression pressure is reduced, and the engine is less economical. In the Diesel engine we can reduce the power by simply reducing the amount of fuel sprayed into the cylinder, as however small an amount is sprayed into the red-hot air it is bound to burn.

The original Diesel engine has been a great deal improved, and now many large engines are made on this principle. Compressed air for spraying in the oil is, however, in many cases being abandoned and the oil is simply squirted in through a very fine nozzle under a pressure high enough to make a very fine spray.

Although the Diesel engine has been very largely used there are certain disadvantages in it. One of these is the very high compression pressure. There are several objections to this. It means a great deal of work done in compressing the charge, and although this work is recovered on the working stroke, yet it means great stresses on all the parts and great pressures on the bearings with proportionate wear. Also the high compression pressure makes any leakage far more serious than with a lower pressure.

Accordingly, engines have been devised in which the air is compressed alone and the oil sprayed in afterwards, but the compression is not high enough for the oil to ignite solely from the heat of compression. In these engines a small part of the combustion chamber is left without a water jacket, and the heat from the explosions keeps this red-hot. The oil is sprayed on to this and evaporates and ignites at once. Otherwise the action of the engine is exactly the same as that of the Diesel.

For starting, this part of the cylinder is heated by a lamp.

The compression pressure of these engines is usually higher than it would be possible to use if the fuel were mixed with the air before compression, but a good deal lower than that necessary in a real Diesel engine. Such engines are called "hot bulb" or "semi-Diesel" engines. Both the Diesel and hot bulb engines can be built on either the four-stroke or two-stroke principle, and, as a matter of fact, large numbers are built on both.

Starting and Reversing. It will be seen from the above description that the ordinary motor is not capable of starting itself, or of reversing. It is, therefore, necessary to make some arrangement for starting and it is also necessary to make some arrangement for reversing the propeller in order to back the boat. There are two distinct arrangements for this. In the one case the engine can be disconnected from the propeller and started independently, while in the other the engine is always connected to the propeller and arrangements are made to start and reverse it when necessary.

For all the smaller types of engine the first type of arrangement is usual. In this case the principle is very much the same as that of the gear of an ordinary motor car, that is to say, the engine is started either by hand or some other means and kept running. Gears are provided to run the propeller either in the same direction as the engine or the reverse way, and these are connected as required, by clutches. To stop the propeller it is disconnected from the engine altogether.

The starting of small engines is still often done by hand, but in many cases they are provided with self-starters, as are the engines of cars. Many of these are electric, like the car starters, and as most modern boats have electric light the starting is combined with the

lighting outfit. In some cases engines are started simply by pumping explosive gas into the cylinders and then making a spark in the one in firing position. In other cases compressed air is used.

The reversing gears used are of very various pattern, but the principle on which they are mainly based is shown diagrammatically in Fig. 7. Here A is the shaft from the engine and B the shaft to the propeller. C and D are two gear wheels; E and F are two chain wheels. As D is driven in the opposite direction to C while E and F turn in the same direction, it follows that F runs in the contrary direction to C, and therefore in the opposite direction to the engine. G is a sleeve turning with B, but sliding on it under the direction of the reversing lever. H and K are two clutches. In the position shown the engine is not connected to the propeller at all and, therefore, it will run idly without the propeller moving. If, however, G is moved forward so as to engage the clutch H the propeller will be driven in the same direction as the engine and the boat will go ahead. If, on the other hand, it is moved backwards the clutch K will be engaged and the boat will go astern.

There are many variations of this, and in some cases the reversing gear is so arranged that the propeller is driven at a different speed to the engine. This is because the speed at which the engine runs best is often different to that at which the propeller is most efficient. Thus, in heavy slow boats the propeller must be large and run very slow in order to be efficient. If a light engine, running fairly fast, is used in such boats it is, therefore, desirable to run it slower than the engine.

In really large engines, such as are used for cargo ships, a gear of the type described would be very heavy and cumbersome, and there would be difficulties in working. It is, of course, impossible to start such

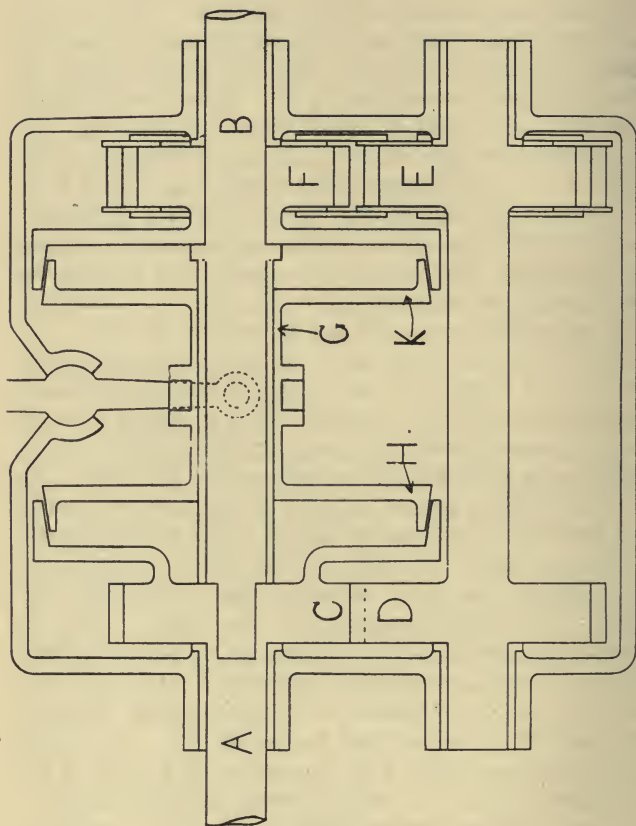


FIG. 7

engines by hand and the electro motor, as used on the small engines, is impracticable. Hence such engines are usually coupled direct to the propeller and are made to run in either direction, being started by compressed air.

In this case, if the engine is of the four-stroke type, arrangements must be made for altering the motion of the valves from one suitable for running ahead, to the opposite. This may be done by having two sets of cams on the cam-shaft and sliding the latter endways. The two-stroke engine has no valves so no alteration is necessary. If the engine is of the injection type the working of the fuel valve must be altered, and if of the mixture type the point of ignition must be altered.

For the purpose of starting, compressed air is stored in a reservoir at a high pressure. It is pumped into this either by a pump on the engine while it is running or by a pump driven by a separate engine. When it is desired to start the engine in either direction the compressed air is admitted to the required cylinder by suitable valves, and the engine starts. Immediately the engine has made one revolution it should fire, and the compressed air can then be cut off and the engine run in the ordinary way.

This arrangement can be used satisfactorily on engines down to 150 h.p. or less. In fact, it seems possible that the reversing engine may come into general use for quite small powers, either electric or compressed air starting being used.

It may be mentioned that in some cases the very small size two-stroke petrol engines, say of 5 h.p. and less, are used as reversing engines simply by starting them by hand in the direction required. As the two-stroke has no valves it will run in either direction, and all the alteration necessary is to alter the time of ignition.

CHAPTER III

COMPARISON OF TYPES OF ENGINE

Two-stroke versus Four-stroke. When we compare the various types described the first question is whether the two- or the four-stroke is the best. At first sight it would appear that the two-stroke had all the advantages, as it has a working stroke for each revolution, whereas the four-stroke has only one for every other revolution. Therefore, the two-stroke ought, theoretically, to give twice the power for the same sized cylinder, all other things being equal, and therefore get more power for a given weight. Another advantage is that as there are twice as many impulses the action is not so jerky. That is to say, that we can get an equally smooth pull with half the number of cylinders.

The question of whether the two- or four-stroke is the best is still a matter of opinion, but the four-stroke has many practical advantages and is likely to remain in use for some considerable time yet.

In the first place, if the action of the two engines is considered, it will be seen that in the two-stroke the exhaust gas has to get out of the cylinder and the fresh gas get in during a very small space of time, while the piston is at the bottom of the stroke, while in the four-stroke a whole stroke is spent on getting the exhaust gas out and another in getting the fresh gas in. The practical result of this is that in the four-stroke the cylinder can be pretty completely cleared of exhaust gas and filled with fresh mixture however fast the engine is run. On the other hand, at high speeds the two-stroke does not get a really full charge of fresh

gas at high engine speeds. For these reasons it is found in practice that, in all moderate-sized engines at all events, more power can be obtained from a given sized cylinder in a four-stroke than a two-stroke. Accordingly practically all engines in which weight per horsepower is of extreme importance, such as motors for high speed boats and aero engines, are made on the four-stroke principle.

The simple form of two-stroke shown has several other practical disadvantages. One is that it is practically impossible to prevent the fresh gas coming into the cylinder from mixing, to a certain extent, with the exhaust gas going out, so that a small proportion of the fresh gas goes out of the cylinder without being used. This wastes fuel. A certain amount of work is spent in drawing the charge into the crank case and compressing it the first time, and this work is wasted. This, again, makes the engine slightly less economical. There are certain difficulties in making the crank case air-tight, especially when the bearings get worn, and this is more particularly the case when there are several cylinders, as the crank case of each cylinder must be isolated from the others.

Some of these objections can be got over by not using the crank case as the charging pump but having a separate one, but this means complication. It is, therefore, not often done in small engines but is very common in really large ones.

On the other hand, the simple form of two-stroke, as shown, is very much cheaper than the four-stroke to make, as the whole of the valves and the gear necessary to drive them is done away with. The engine is also the simplest possible, and has hardly anything to get out of order as there are no working parts except the piston and connecting rod. For these reasons it is

made in very large numbers for the smallest sized marine motors, as here the extra amount of petrol burnt is of small importance, and low first cost and simplicity are very important.

Curiously enough the other application of the two-stroke is mainly for engines of very considerable size. This is because in larger engines the fuel is not mixed with the air before it goes into the cylinder but sprayed in afterwards. Also such engines are usually used for cargo boats, and in order to be durable are run at a very slow speed.

Under these circumstances a great many of the disadvantages do not appear. Thus, as air alone is compressed in the cylinder, and no fuel is mixed with the air till the end of the compression stroke, no fuel is wasted if a little of the air escapes direct through the exhaust port.

Again, with comparatively large engines working at a moderate speed there is less difficulty in making the crank case air-tight. Then, again, in really large engines a separate pump is usually used for charging, and in this case it can be made larger than the cylinder so that an excess of air is blown through and the exhaust thoroughly washed out. In large engines running at slow speed, there is no difficulty in getting the exhaust out and the fresh charge in during the time available.

At the present time the question of the four-stroke *versus* the two-stroke is, however, purely a matter of opinion. The future will decide whether the one or the other comes into general use for all purposes or whether both the two-stroke and four-stroke will remain in use for different purposes. In the immediate future the latter is likely to be the case.

Gas Mixture versus Diesel or Hot Bulb. The other great division among marine motors is that between

those in which the fuel is mixed with the air before the latter is taken into the cylinders and those in which the air alone is compressed and the fuel sprayed in afterwards.

The advantages of the injection type are—

1. The compression pressure can be higher, and therefore less fuel is burnt for a given power.
2. Any kind of oil can be used, hence the fuel is cheap.
3. Two-stroke engines can be used without loss of fuel through the exhaust.

The disadvantages of the injection type are—

1. As the compression is high the stresses on the parts are also high. This means the engine is heavier for a given sized cylinder.
2. Combustion is not so rapid, and therefore there is a limit to the speed at which the engine will run.
3. In a small engine the amount of fuel which has to be injected at each stroke is very small, and pumps supplying this accurately at high speeds are very delicate.

The fact that the injection type can only be run at moderate speed, combined with the heavier stresses due to the higher compression, make it considerably heavier per horse-power than the type using vaporized fuel.

For all the above reasons the type vaporizing the fuel is therefore preferable for the smaller sized engines, and particularly those which run at a high speed. It is also preferable where weight is a great object.

In the majority of these cases the cost of fuel is not of serious importance. Hence it will probably remain in use for a long time for very small sized engines for all purposes and for pleasure boats of moderate size. It will also remain in use for very high speed boats.

On the other hand, for purely commercial work, especially cargo boats, the cost of the fuel is of very

great importance, and the engines are run at slow speed both in order to reduce the cost of repairs and also to suit the propeller. Weight is of less importance and the cylinders are of considerable size. The pumps cease to be so delicate, and there is time for the oil to burn properly. Hence the injection type of engine is, in every way, the most suitable.

CHAPTER IV

ADVANTAGES OF MOTOR BOATS

HAVING seen the fact that the marine motor has developed and come into very considerable use, it may be asked what are its special advantages? Steam has been in use for a very long time and has proved a very satisfactory means of producing power. Why should we give it up for anything else?

The essential reasons which have brought the marine motor into use differ rather in the different sizes, but are all dependent on essential principles. They all depend, in fact, on the much greater efficiency of the machine and the fact that it is simpler.

All engines burn a certain amount of fuel and turn a part of the heat produced into useful work, the rest being wasted. In a steam engine the fuel is used to turn water into steam, and this is then used in an engine to do work. In the motor the fuel is burnt direct in the cylinder of the engine. For various reasons, which are too technical to give here, the losses in the steam engine are much greater than those of the I.C. motor, and therefore the latter uses less fuel for the power produced. This is especially the case when the steam engine is made very light and of small size, as such steam engines are very extravagant, while small and light I.C. motors are very little more extravagant than large and heavy ones.

The I.C. motor is also a very much simpler machine than the steam engine, with its needful parts. In both cases there is an engine with a piston, crank-shaft, and valves, but the I.C. engine is not more complicated than

the steam engine itself. The steam machinery, however, has to have, in addition to the engine itself, a boiler which has a great number of joints under pressure. Sea water cannot be used in the boiler, so that it is necessary to have a condenser to condense the steam so that it can be used over again. Pumps are necessary for circulating the water through the condenser, feeding the boiler, etc.

All these parts are heavy, and the result is that if made equally substantially the steam machinery weighs a great deal more than the marine motor.

For the same reason the space taken up by the marine motor is considerably less than that taken up by steam engines, boilers, etc., of equal power.

In addition to these advantages the I.C. motor needs less attention when running, and also can be started without waiting to get up steam.

With regard to the question of weight and economy, it is usual for engineers to express these in terms of the weight of the machinery for each horse-power developed, "weight per horse-power," and to express the fuel consumption in terms of the amount of fuel burnt for each horse-power developed for an hour, "lbs. of fuel per horse-power per hour."

The "weight per horse-power" of ordinary steam marine machinery varies from about 40 lb. per horse-power in the lightest machinery used in high speed boats, such as torpedo craft, to about 500 lb. per horse-power in the large and very substantial machinery used in tramp steamers.

Generally speaking, the weight per horse-power of all kinds of machinery gets greater as the size increases, the machinery being, of course, equally substantial in each case.

If we take ordinary marine steam machinery, such as

is fitted into steam launches, say from 10 to 500 h.p., we find that the lowest weight for any practicable machinery is not much under 40 lb. per horse-power, this being the weight of the torpedo boat machinery. In order to get the weight as low as this the engines have to be run very fast and the boiler driven very hard under forced draught. This makes the consumption of fuel very high, while the stoking must be good or the boiler will not keep steam, and the machinery generally takes a great deal of keeping in order. Ordinary steam machinery of this size, built not to require specially skilled attention, usually weighs over 120 lb. per horse power.

On the other hand, marine motors suitable for really high speed boats can be built to weigh under 8 lb. per horse-power. Quite substantial marine motors, requiring no special skilled attention to keep in order, can be built to weigh from 20 to 50 lb. per horse-power. This is a saving of at least 70 lb. per horse-power over ordinarily substantial steam machinery, or nearly $3\frac{1}{2}$ tons in an engine of 100 h.p.

To put the matter another way, if we have a really high speed boat driven by steam with 100 h.p. we can put in a marine motor of over 400 h.p. without any increase in weight and get a very great increase in speed. Similarly, we can increase the power of a cruiser with a more substantial type of machinery.

The same applies to the space taken up. We can, in the motor boat, therefore, either get the same power in very much less weight and space, or alternatively without increasing either the weight or space taken up, get some four times the power. With regard to the fuel consumption, very much the same proportion applies. Steam engines of these small sizes probably seldom burn less than 3 lb. per actual brake horse-power per hour.

It is quite easy to make a marine motor of the same size burn under $\frac{3}{4}$ lb., or less than a quarter of the weight of fuel burnt by the steam engine. Further, the fuel consumption of the steam engine may be considerably increased by bad stoking, while the motor is practically automatic and independent of skilled attention while running.

Further, the ordinary steam engine burns coal, and therefore there must be a stokehold separate from any other part of the boats for stoking. This is also apt to be a dirty job, so some one man must look after it.

In small sizes also the marine motor is a great deal cheaper to build than the marine steam engine. There is nothing but the engine, while in the case of steam there is the boiler as well. First cost is a great consideration in many cases and, in fact, often determines whether power can be adopted at all or whether it must be dispensed with. For all these reasons the motor has rapidly displaced the steam engine for small boats, launches, etc.

The motor has, however, another great advantage, and that is that it is practicable to make it commercially in very much smaller sizes than it is practicable to make a steam engine. The latter, if built to weigh less than 3 or 4 cwt., becomes a toy which is very expensive to build in proportion to the result obtained. Further, all the parts are very small and the machine hardly a working proposition.

The petrol motor, on the other hand, can be made down to a very small size and yet be a practical proposition, both from the point of view of working, when it is made, and of manufacture in the factory. Quite practicable marine motors are made weighing under $\frac{1}{2}$ cwt. giving some 3 h.p. Some of these, before the war, were sold for under £20.

The field for these small motors is very large and could never be filled by steam engines. They can be fitted into a very large number of boats of such small size and light construction that steam engines would have been quite inapplicable on account of the weight, even if the cost of the latter were not prohibitive. Both for business and pleasure, therefore, the marine motor has not only replaced the steam engine in the small sizes but has also supplied a want that the steam engine could never have filled.

A special use of the motor, which is rapidly extending, is as an auxiliary installation in sailing boats. Auxiliary machinery of the steam type has frequently been fitted into sailing boats but has never been a complete success. This is because the weight of the steam machinery usually distinctly interfered with the boats sailing capabilities, while the space taken up also destroyed the great advantage of the sailing boat, which is that there is no room taken up by the machinery. With the advent of the motor, however, it became possible to fit machinery into a sailing boat capable of driving her 5 or 6 miles an hour in a calm sea without any material space being taken up or weight added which interfered in any perceptible way with her sailing. Thus, the advantages of the sailing boat are retained and its one real objection, namely, that it cannot proceed in a calm, is got over.

For all the smaller classes of boats, therefore, the great advantages of the marine motor are really that it will do things which are impossible with steam and which are badly wanted. In the actual cost of fuel there is usually little or no advantage, for although the weight of fuel burnt is very small it is of an expensive type, for reasons which will be explained later.

When we come to really large ships the conditions

are somewhat different. Here the steam engine has, till lately, been practically universally employed as a motive power, the only exception being a very small number of sailing ships. Steam has, on the whole, been quite satisfactory and has done all that was necessary. Hence, in order to come into use the marine motor must do all that steam will do, and do it better or more economically.

Now the majority of large steam ships are used to carry cargo from one place to another and frequently make long voyages. In order that the motor ship should be more economical it is necessary either (1) that it should cost less to run, or (2) that it should be able to carry more cargo for a given sized ship. The marine motor helps in both these ways.

With regard to the cost of running, the weight of fuel burnt by a large marine motor is well under $\frac{1}{2}$ lb. per horse-power per hour. That of the most economical steam machinery in practical use is from two to three times this. With regard to the price of fuel coal has been, up to date, cheaper than oil; but coal lately has risen enormously in price. A great consideration in the matter of cost, however, is the fact that coal requires a great deal of labour in stoking, whereas oil can be pumped mechanically where it is required. Hence when oil is used a great deal of labour on the ship can be dispensed with.

For this reason quite a large number of steamers have been converted to using oil fuel in the boilers. Using oil in a steam boiler is, however, a very makeshift arrangement, for over twice as much oil per horse-power is used in this case as is used if it is burnt in an I.C. engine.

Here, therefore, there is a very distinct saving in running cost by use of the marine motor, for the fuel

in the larger sized motors is the same as that burnt in the boilers of the steamer and less than half as much is burnt.

In addition to this the motor takes up less space and is lighter than the steam machinery. This means that the motor ship can carry more cargo than the steam ship of the same size. The saving in the weight of fuel burnt also allows of more cargo being carried. Thus, if we take the case of the large cargo ship, a motor ship may burn, let us say, 15 tons less fuel a day than a steam ship. The advantage of this will vary according to the length of the voyage. On a short voyage the advantage will be small. Thus, if we take the case of a large motor ship and steam ship of the same size, and assume that the motor ship burns 15 tons a day less fuel on a two days' voyage, the saving will only be 30 tons. On a six weeks' voyage, however, the saving will be 630 tons, and therefore the motor ship will be able to carry 630 tons more cargo in addition to the extra cargo it can carry from the weight saved in the machinery.

We see, therefore, that the marine motor has the advantage over the steam engine for boats of every size in which it is practicable to use it. Various difficulties have had to be got over in adapting the I.C. motor to marine work, some of which will be dealt with later.

Naturally, it has been easier to get over these in the very small sizes than the large ones, largely because there had been a great deal of experience in small motors, both for stationary work and also for motor car work, before the marine motor developed, and the experience in these was very helpful. Experimenting is also a very much cheaper thing to do in small work than in large work, and the result of breakdown is much less

serious in the case of small boats than large ones. In the latter especially it is wise not to be in too great a hurry to progress as a failure may give a good principle a bad name. Nevertheless, the marine motor has been thoroughly successful in units up to some thousands of horse-power. There is at the moment a difficulty in making motors of over a certain size, but there is little doubt that with greater experience engines of any size desired will be practicable.

It must always be remembered that even with steam engines there has always been a limit to the practicable size, and that there was a time, not so very long ago, when no one was prepared to build a 5,000 h.p. steam engine.

CHAPTER V

FUELS FOR MOTOR BOATS

PRACTICALLY all the fuel used in motor boats is oil, and at present virtually all is mineral oil of some kind. Various other fuels are possible in the future but have not yet come into use. Alcohol is believed by many to be the future fuel for small powers, where a liquid which vaporizes easily is necessary; but so far the use of alcohol has not made great headway, even on the Continent, where some of the governments have made great efforts to induce people to use it. On land, coal is used very largely for I.C. engines, being completely converted into gas, called "producer gas," and this may be extensively used for marine work in the future, but has not come into use to any material extent at present.

Various other fuels have been suggested and used on a small scale, but at present the bulk of the fuel used comes from crude petroleum in one form or another. Crude petroleum consists of a mixture of oils, some of which are very volatile and are called "spirit," and some the reverse. Roughly speaking, the more volatile the oil the lighter it is, i.e. the lower its specific gravity. These are separated from each other by distillation. The crude oil is put into a boiler and heated. Soon it begins to boil and the more volatile contents come off as gas and are condensed by a cooled pipe. When all the very light oil has boiled out of it the temperature is raised and oil of a higher boiling point comes over. By this means the crude oil is separated into various grades, each of them heavier and less volatile than the last.

Details of these processes will be found in works dealing with oil.

For general purposes of description as far as fuel purposes are concerned we may, roughly speaking, divide these various grades into three classes, namely, petrol, paraffin, and fuel oil.

Petrol. The most easily evaporated of the motor fuels in common use is petrol, which is also known as motor spirit, and in America is called "Gasoline," or sometimes for short "gas." This is a very light petroleum having a specific gravity of from $\cdot 700$ to $\cdot 750$ as a rule, and is so volatile that it will completely evaporate in air of ordinary temperature, that is to say, that if a small quantity is spilled on the ground it will completely dry up in a few minutes. Really good petrol should be about $\cdot 700$ gravity and should dry very rapidly without leaving any unevaporated oil at all, and the petrol supplied for cars some twenty years ago was of this quality. As the use of cars extended, however, the demand for petrol got so great that there was not enough of this very light spirit to go round and accordingly heavier and less volatile spirits had to be included in the ordinary commercial product. In fact some of the modern petrol contains a certain proportion of what is really paraffin, which will not evaporate at all at ordinary temperature.

The usual way of using petrol is to spray it into the air in the inlet pipe before it goes into the cylinder. The air is travelling along the pipe at a very high velocity, and as the petrol is sprayed into it in a very fine spray it evaporates practically instantaneously, and by the time it has passed through the inlet valve into the cylinder it should be thoroughly evaporated and be a practically perfect gas.

The usual way of effecting this spraying and

evaporation of the petrol is to feed it into the inlet pipe through a "carburettor." The ordinary carburettor is of what is known as the float feed type, and in its simplest form is shown in Fig. 8.

Petrol enters the float chamber (A) through a needle valve (B) which is closed when the petrol reaches a certain level by the float (C), the action being exactly the same as that of a ball valve in a water cistern. The jet (D) is connected to the float chamber (A), and is placed in the centre of an air nozzle or "choke tube" (E), the top of the jet being just above the level of the petrol. The air entering the cylinder is drawn through the choke tube in the direction of the arrows, and when this is done a vacuum is formed at the top of the jet and the petrol is sucked out in a fine spray. This mixes with the air and rapidly evaporates. A throttle valve (F) is placed in the outlet to reduce the engine speed when necessary. Theoretically, the amount of petrol sucked out of the jet should be exactly proportionate to the amount of air drawn through the choke tube, that is to say that the proportion of petrol and air should be constant whatever the rate of flow through the carburettor. In practice, however, this is not the case with the simple carburettor shown, and the more rapid the flow of air the greater the proportion of petrol to air.

It is necessary in practical work that the engine should be capable of running satisfactorily not only at full speed with the throttle full open, but also at lower speeds and with the throttle partly shut. With the simple form of carburettor shown this is not practicable, for if the mixture of petrol and air is right at full power the proportion of petrol to air will be too small when the engine is throttled and the mixture will fail to explode. Hence, in practice this simple form is modified, generally by the introduction of a small auxiliary

choke tube and jet, especially for slow running and other devices, to keep the mixture the same proportion at all rates of flow. These vary a great deal in principle, and are mostly patented specialties of different makers.

Paraffin. Although petrol has many advantages for the use of marine motors it has certain disadvantages, which will be discussed in the comparison of the various fuels. Accordingly ordinary lamp oil, or what is commonly called "paraffin," is used to a great extent. This is too well known to need much description. It is a clear liquid oil with a specific gravity of about .800 to .830, and will not evaporate in air at ordinary temperature. It cannot be used in a carburettor of the type described for petrol, therefore, as it would not evaporate and it is impracticable to make it into a spray fine enough to explode. Where it is used in the ordinary motor it is therefore heated to such a heat that it will evaporate. The usual arrangement is to have a carburettor very much like that used for petrol, but to pass the mixture of paraffin and air through a hot vaporizer placed between the carburettor and the inlet valve. This vaporizer consists of a chamber heated by the exhaust gas, and in this the paraffin is vaporized. Some means must be taken to heat the vaporizer to start the engine. This can be done with a lamp. In some cases the engine is started by petrol, and as soon as the vaporizer has got hot from the exhaust the paraffin is turned on in place of the petrol.

The exact arrangements of such vaporizers vary a good deal, being the specialties of different makers.

Fuel Oils. After the petrol and paraffin have been distilled off heavier products are left. Some of these are used to make lubricating oil. There are, however, a considerable variety of very heavy oils produced which are only suitable for burning, and which may therefore

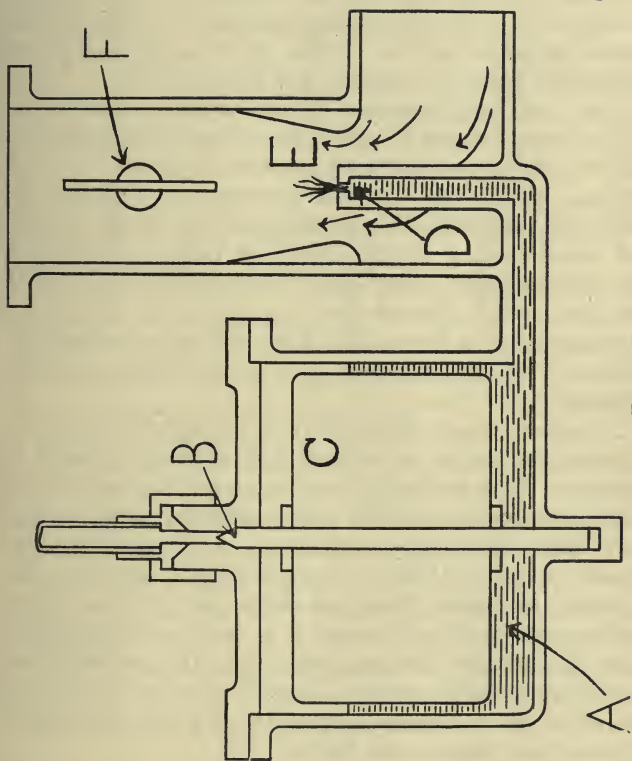


FIG. 8

be termed "fuel oils." These are very heavy and non-volatile oils, often even tarry, and it has been found very difficult to vaporize them in any form of vaporizer of the type used for ordinary paraffin. The main difficulty is to avoid tar being deposited in the various working parts and the inside of the cylinder, as tar interferes with the engines working properly.

Such oils can, however, be used quite successfully in that class of engine in which the oil is injected after air alone has been compressed, i.e. the Diesel and hot bulb types. For these it is not necessary to vaporize the oil at all, and under the pressure and heat at the moment of injection any combustible will burn completely if made into a fine enough spray. Naturally, the fuel oils are very much cheaper than any others, as they are in the nature of a by-product from the more refined oils. Hence they are generally used for the injection type engine.

Producer Gas. As coal is the cheapest fuel for its heating power it is natural that attempts should be made to use it in the I.C. motor, as we then get the low fuel consumption of this type combined with a cheap fuel which we produce ourselves. Attempts have been made to use coal direct by grinding it into very fine powder, and when Diesel produced his injection engine he appears to have intended it to use coal dust sprayed into the cylinder by compressed air. This has so far not been successful in practice, one objection being that coal contains a considerable amount of gritty ash which wears the cylinder and piston.

On land, however, coal is very largely used by being made into "producer gas" and then used in the ordinary gas engine. Producer gas is different from ordinary coal gas because in the latter only part of the coal is made into gas, the greater part being left as coke. In

producer gas the coal is fed into a vessel which forms a closed furnace and air and steam are forced or sucked into the bottom, the gas coming out at the top. The volatile products of the coal are distilled off and form ordinary gas. The steam is split up, the oxygen combining with part of the carbon to form carbonic oxide, which is a combustible gas, and the hydrogen being set free. The rest of the carbon combines with the oxygen of the air and forms carbonic oxide also, and in doing so gives off enough heat to keep the whole red-hot. The nitrogen goes through unaltered. This produces a very cheap gas which is largely used for heating furnaces and for stationary engines.

Practical reasons have prevented this type of gas being used to any great extent for marine work so far, but a certain number of marine motors have been made to work with it, and it is possible that it may come into more extended use, this depending very largely on the relative price of coal and oil in the future.

With regard to the comparative advantages of these fuels we may, for the time, disregard coal, as its use is very small, although, should the price of coal fall, it is quite likely it may be more used in the future.

For all the smaller types of marine motors, and in all cases where weight is of extreme importance, there is no doubt that petrol is by far the most convenient fuel, in fact it is technically in every way the most satisfactory. It is very easy to evaporate, hence the engine can be started at once without any preparation. As it evaporates completely in air at ordinary temperature the mixture of petrol and air goes into the cylinder in the form of a practically perfect gas, and this can be compressed to a high compression pressure without danger of pre-ignition. The mixture, being a perfect gas, burns very rapidly and therefore the combustion is complete in a

very short time. This is very important when a great deal of power is required on a small weight, as in this case it is essential to run the motor very fast, for reasons which will be seen later, and a slow burning mixture will not burn in the time available. The charge does not have to be heated before being drawn into the engine, which is an advantage, for we have seen that the power of an I.C. engine depends on the difference of temperature before and after ignition, and therefore any heating before ignition reduces the power which can be obtained.

For all these reasons considerably more power can be obtained with petrol for a given sized cylinder than with any other fuel.

Further, the petrol burns very completely and cleanly in the cylinder and there is no trouble with products of the nature of tar depositing there.

There are two great objections to petrol. In the first place it is very expensive owing to the fact that there is only a limited supply of it and that there is an enormous demand for motor cars. In the second place, the very fact that it is volatile makes it dangerous unless carefully handled. When petrol is accidentally spilt, for instance, it evaporates and forms an explosive mixture with the air. This mixture is heavier than air and, therefore, in a boat, stays in the bottom. Should it accidentally be set alight it explodes, and may set the whole boat on fire from end to end in an instant. This happens occasionally with motor cars, but the worst here is usually the loss of the car. It is much worse in the case of a boat, as if it should occur some distance from land, and no help be near, it may mean the loss of the lives of all on board.

The avoidance of this danger is, however, simply a matter of avoiding leaks in the petrol tanks and connections and of care in handling the fuel.

Accordingly, petrol is used for many of the small sized motors here, and is also used for all boats where high speed is of importance. In America, where petrol is cheaper and money more plentiful, it is used very largely for motor boats up to about 500 h.p., even where speed is not of very great importance.

In England, however, paraffin is very largely used for engines over about 25 h.p. The advantages are that it is safer and that it is about half the price of petrol. The consumption of paraffin per horse-power is not greater than that of petrol, but the power which can be got out of a given sized cylinder is considerably less; generally speaking, about 20 per cent less. This is partly because the charge of gas and air has to be heated to vaporize the paraffin, and partly because the paraffin engine cannot be run with such a high compression as the petrol engine. Another disadvantage is that the vaporizer has to be heated before the engine can be started. A still further disadvantage is that it is much more difficult to get really complete combustion, and the inside of the combustion chamber is apt to get coated with tarry products, which may prevent the electric spark from firing the charge properly, and may cause the valves to stick. Unless the engine is kept clean it is also liable to get a little paraffin on the hot parts and this makes it smell.

Technically, far the best way of heating the vaporizer is to start the engine with petrol and let the vaporizer get heated by the exhaust gas, as in this case the whole engine, as well as the vaporizer, gets heated up before the paraffin is turned on. In this case it is much easier to keep the inside of the combustion chamber free from tar, etc. As far as economy goes, this is practically as cheap as heating the vaporizer by a lamp, but it has the disadvantage that petrol must be carried on board, and

a little petrol is practically as dangerous as a great deal.

All the above difficulties can be got over, however, with well-designed engines and care in running, and there is no doubt that the paraffin motor is perfectly practicable, and safer and cheaper to run than the petrol one. It will, therefore, probably have a great vogue where light machinery is required but extreme speed is not necessary.

Fuel oil is mainly used in engines of the Diesel and hot bulb types, as the difficulties of vaporizing it so effectively as to avoid the deposit of tar in the cylinders are much greater than in the case of paraffin. There are great difficulties in running the injection type of engine very fast owing to the difficulty of getting the pumps to work properly, and also the fact that the combustion of the spray takes time. The very high compression also makes the engine heavy for the size of the cylinder. Very small cylinders are also not very satisfactory for many reasons ; hence we cannot make a powerful engine by using numerous small cylinders as is done on the powerful petrol and paraffin engines, where weight is of importance.

The Diesel and hot bulb engines are, therefore, in practice usually several times as heavy per horse-power as the petrol and paraffin engines, even of the moderate speed types. On the other hand, the injection engines only burn about two-thirds the amount of fuel per horse-power that the petrol and paraffin engines do, while the fuel is very much cheaper. Hence they are the most economical in running, and are used where this is the essential point and lightness not important.

Fuel for Naval Motor Boats. In the Navy the conditions are not quite the same as for other purposes as cost is of little importance, and therefore the choice of

fuel depends on other considerations. For practically all the surface boats used in the war petrol was used as fuel. In such high speed boats as the coastal motor boats petrol was essential to get the power required for the high speed, and this high speed was absolutely necessary to make the boats of any practical use. Cost was a minor consideration, and as regards the risk, this is very small with care in handling, while war is inevitably a game in which risks must be taken. With regard to the slower motor launches, petrol is no doubt the most convenient fuel, for the reasons stated above, and it was accordingly used. Whether this was desirable, in view of the shortage of petrol which was stated to exist, seems very doubtful.

In the submarines, petrol is not considered desirable on account of the danger, and accordingly the engines all use heavy oil and are usually of the injection type.

CHAPTER VI

ENGINE SPEED, POWER, AND WEIGHT

IN order to appreciate the essential differences between the different types of motor in use for marine work it is necessary to have some idea of the means by which one engine is made a great deal lighter than another. This question does not arise in the motors made for motor cars to any great extent, as these are all made sufficiently durable to last for a reasonable time, and are all used in very much the same way. They are all made as light as they can conveniently be made consistently with this durability, and consequently all have settled down to very much the same type of construction.

In the marine motors there is a much greater range of requirements. In some cases speed in the boats is the most important consideration, and practically everything has to be sacrificed to this. Speed means great power and small weight. On the other hand, there are cases where absolute reliability and great durability are essential but weight of little importance. This is, for instance, the case in a cargo ship where the engine may be required to run for six weeks continuously at full power without stopping, and where a breakdown of the engine may mean the loss of the ship.

Now, the power which any sized engine will give depends primarily on the speed at which it is run. It is not at first sight clear why this should be so, but a little consideration will show it.

Let us take, for an example, a steam locomotive running on a railway, and drawing a train. If it goes 20 miles an hour it takes a certain amount of power.

Suppose we want to go 40 miles an hour instead. Obviously the wheels will go round twice as fast and the pistons will have to make twice as many strokes, while the pressure on the piston will have to be the same, as the resistance of the train will be at least as great at 40 miles an hour as at 20. As the pistons have to make twice as many strokes a minute, and each stroke must do the same work, twice as much work will be done in a given time and the engine will be giving twice as much power. The cylinders will have to be filled with steam twice as often and, therefore, twice as much steam will be used. It is for this reason that engines which have to do their work at slow speeds, such as goods engines, have smaller wheels than those which run fast, like expresses. If the goods engines had wheels the same size as the express engines they would not give the required power unless the cylinders were made larger.

The same is true of everything. We all know, for instance, that it is harder work to run fast than to walk slowly. The same is true of a shaft being turned. Let us take a case of a simple crane which has a rope wound round a drum with a handle on it and a weight suspended on the rope. The resistance to turning the drum with the handle will be the same at all speeds ; but we all know that it takes more power to wind up the weight quickly than slowly.

It is not intended here to give the formula for calculating the power an engine is giving, as this will be found in engineering text-books, but only to point out the fact that, other things being equal, the power an engine gives is proportionate to the revolutions per minute.

Hence, an engine of any given size will give more power the faster it is run, provided that the pressure on the pistons can be kept the same. There are certain limits

to the speed any particular engine will run, one of the principal of these being that the valves will only allow a certain amount of gas to flow through them. Valves can, however, be made large enough for speeds higher than are desirable in practice and, granted that the engine is designed for it, most types of engines can be run faster than it is desirable to run them.

This is obviously the easiest way of reducing the weight of the engine per horse-power. If we want to get more power out of an engine without increasing the weight the most obvious thing to do is to run it faster, making the valves larger if necessary. The weight of the engine will then remain practically the same but the power will increase, and therefore the weight per horse-power will be less.

Accordingly, in all cases where weight is of importance, engines are run very fast. There are, however, limits to the speed which is practicable. As the speed increases so does the friction of the bearings, and there comes a point when it is difficult to keep them from running hot. Furthermore, it is obvious that the faster an engine is run the greater the wear and tear.

In addition to running an engine faster to reduce the weight per horse-power it is, of course, possible to reduce the weight of the various individual parts. In some cases this is done by using stronger or lighter material, as, for instance, in the case of engines in which forged steel is used for the cylinders in place of cast-iron, or in which aluminium is used for various cast parts. In many cases, however, where really light engines are needed, parts are reduced in strength. This means that reliability and durability are partially sacrificed to lightness.

Hence we get to totally different ideals, the one being a very light engine indeed, and the other an extremely

durable one. The first type of engine will run at a very high speed, probably between 1,500 and 2,000 revolutions per minute. Every part will be made as light as it possibly can be regardless of expense, and the margin for durability will be very small. Within reasonable limits such an engine will be quite reliable, that is to say, that if kept in good order it should be able to run a considerable number of hours without breakdown. To get good results, however, it will need a great deal of attention from really skilled men. This is, in fact, an engine of practically the same type as the aero engine, which was wonderfully reliable in the air but required something like a complete overhaul between each long flight. Even when very well looked after the life of this type of engine is extremely short.

At the opposite end of the scale is the type in which extreme durability has been made the one great consideration and weight has become quite a secondary point. In this case the speed is very slow, in some of the really large cargo ship engines under eighty revolutions per minute. Such engines are for all practical purposes absolutely reliable, and last almost for ever. A motor in a large cargo ship may have to run for quite six weeks without stopping at all and, of course, runs at its full power all the time. It must not only be able to do this now and then on occasion, but it must be absolutely certain of doing it whenever required, and under no circumstances must it break down. This is a matter of very great importance. At sea there are a great many cases where a breakdown of the engine may mean the loss of the ship. In a bad gale, for instance, the breakdown of the engine means that the ship ceases to be under control, which is a very serious matter; while, of course, if near land the loss of engine power may be still more serious.

Not only must the engine be absolutely certain of making such long runs, but it must not need constant overhaul, and it must run for years without wanting important spare parts.

There are plenty of steam engines of large power running perfectly well which are thirty or forty years old, and which have had very little done to them. There is no reason why the oil engine should be less durable provided the speed is kept low and all the parts are of ample size for the work they have to do. As a matter of fact, there are numbers of stationary oil engines which have run for many years ; in fact there are numerous instances of these having been replaced by new ones, not because they were worn out but because they were obsolete.

The difference in the weight per horse-power in these two extreme types is very great. The aero engine weighs very little over 2 lb. per horse-power developed, and such engines have been used in racing motor boats where it is of extreme importance to get the very highest speed for a race, and any durability beyond that necessary to run the race is uncalled for. On the other hand, engines of the same power, but built solely for durability, will weigh quite 150 lb. per horse-power, or seventy-five times as much. The engines for large cargo ships will weigh a good deal more still. Either type of engine can be built in powers of any reasonable size required.

Between these extremes, engines can be made of any weight per horse-power with a proportionate amount of durability. For instance, the engines of the high speed motor boats used in the war were not as light as the aeroplane engine, but weighed some 6 to 8 lb. per horse-power. Such engines require less looking after than the extreme light weight aero engine, and under

the conditions of the rough work the motor boats had to do were more satisfactory.

For a very large proportion of the work which motor boats of the smaller sizes are required to do, such, for instance, as pleasure cruisers, passenger boats of moderate power, etc., an engine of fairly substantial construction running at a moderate speed is the best, as it combines good durability with moderate weight, say 30 lb. per horse-power in the small sizes and more in the larger. Such machinery will enable good speeds to be obtained without the weight or space taken up being excessive, and at the same time can be made quite durable.

For the boats carrying cargo at slow speeds we get to the extreme of the heavy engine.

It is very important to realize that lightness and durability are opposed properties, and that we cannot attain the one without a certain sacrifice of the other. As greater experience is gained the two can be combined to a greater extent. This has, of course, happened in the past. Modern motor cars are much more powerful in proportion to their weight than the older ones, and yet are more reliable. So are modern locomotives. The marine motor can be made much lighter per horse-power than the marine steam engine, and yet equally durable. Whatever the type of boat used lightness, as far as is consistent with the required durability and reliability, is an advantage, as it means that more weight can be devoted to other purposes.

There is, therefore, no doubt that in the future the weight of any particular type of marine motor will gradually be reduced.

CHAPTER VII

HOW A HIGH SPEED MOTOR BOAT SKIMS

THE development of the very light petrol motor has enabled a principle of construction to be applied to high speed boats, the advantages of which have been known theoretically for a long time, namely the "hydroplane." This must not be confused with the "hydro-aeroplane," which is simply an ordinary aeroplane fitted with floats in place of wheels.

In the case of any ordinary boat, the weight of the water displaced by the boat equals the weight of the boat. That is to say, the hole the boat makes in the water represents the weight of the boat. Hence, bodies heavier than water cannot float. When a boat travels at any ordinary speed it still makes a hole equal to its weight, and the water has to be pushed out of the way to allow the boat to move. At high speeds this causes great resistance.

A body moving very fast may, however, stay at the top of the water without displacing its own weight and, therefore, without making such a large hole in the water. In fact, it may stay on the top and make a very small hole in the water indeed. We can see an instance of this if we take a flat stone and play "ducks and drakes" in quite smooth water. After making a certain number of hops the stone will skim along the top of the water for a little while till the speed gets too low for it and it sinks. Obviously, if it were kept moving at full speed it would skim for ever. Yet the stone is far heavier than the water and sinks directly it loses speed.

The skimming boat, which is always used in motor

boats where really high speeds are required, acts exactly like the stone in the ducks and drakes, but is, of course, so arranged that it does not sink when at rest. As early as about fifty years ago it was proposed by the Reverend Ramus to use a boat with inclined planes on the bottom, so arranged that when the boat was travelling she would lift right out of the water and travel on the planes. It was found in practice, however, that in those days there was no advantage in the arrangement for it is necessary that the planes should be small and the boat driven very fast in order that there should be any gain in speed. In order to get the speed necessary to make her "lift," in fact, it is necessary to have very light and powerful machinery, and until lately no such machinery was available.

When the petrol engine began to be used for racing boats, however, much higher speeds were obtainable. All really high speed boats lift out of the water to a certain extent, and the idea again recurred to men's minds of making them of such a shape that they would lift right out and skim. By this means the hole which had to be ploughed in the water would be very much reduced, and also the surface of the boat in contact with the water made smaller. A great part of the resistance of a boat at high speed is due to the friction between the water and the skin, so if we can reduce the surface in contact we can reduce the resistance.

Various arrangements were tried and some very high speeds obtained, but in many cases the boats were made perfectly useless for any practical purpose. Thus, in some cases the bottom was quite flat, like a punt, with a suitably inclined plane to make her skim. In others the bottom was quite flat in cross section but longitudinally shaped like a saw, so that there were a series of inclined planes.

Most of these boats had very serious objections except for the purpose of winning races. Thus, the flat bottom is a very weak structure and unless the water was quite smooth, hammered on it. The result was that it was difficult to make the boats strong enough to encounter even small waves without making the boat too heavy. When the flat bottom of the boat hit a wave at speed, the strains were very high and damage was sometimes done ; in fact there is an instance of a racing boat hitting a wave with the result that the engine broke through the bottom of the boat altogether and sank.

A further difficulty in some of these types was also that they were very inefficient at speeds below that at which they lifted and skimmed. If we take the case of a flat bottomed boat, for instance, with a series of inclined planes, there will be a sort of flat wall behind each plane. This boat will have very little resistance as long as she is really skimming, for the water will not fill the spaces behind the planes. When going at such a speed that she does not skim, however, the resistance will be enormous. This is a very serious objection in any boat used for practical work as it is generally desired to cruise long distances at moderate speed, as the fuel consumption at high speeds is very great. Unless the boat has a moderate resistance at low speeds, however, this cannot be done satisfactorily.

Further, for many purposes it is necessary that the boat should be fairly seaworthy. It is not possible to drive a small boat of any kind really fast in anything of a heavy sea, but it is necessary that the boat should be capable of living if driven slowly, unless it is to be used solely for smooth water. Many of the types which have been tried for racing are quite unseaworthy as they will not lift properly to the waves, and also

the large flat surfaces are liable to be broken up by hammering on the seas.

It is, however, possible to make a boat which combines the round shape, which has been found the strongest and most seaworthy, with a suitable plane to make it skim, and it is also possible to make such boats so that they are very efficient at moderate speeds as well as their skimming speed. Before the war such boats were built for racing and cruising, and this is the type, which was used for the coastal motor boats in the war.

The principle of such boats is shown quite diagrammatically in Figs. 9 and 10.

In this case the boats are, generally speaking, of the shape of the ordinary boat, but there is on the bottom an inclined plane (A) which is placed slightly in front of the centre of gravity of the boat. The after part is quite flat and curves slightly down at the stern. When the boat is at rest she floats in the water in the ordinary way, as shown in Fig. 9, and at ordinary speeds she ploughs through the water as usual and behaves very much as the ordinary motor launch does. When driven at a really high speed, however, she lifts on the step (A) so that the hull is practically entirely clear of the water, as shown in Fig. 10. Theoretically, there is no reason why she should touch at all anywhere else, but in practice it is very difficult to balance the whole weight of the boat on one point, so the weight is so arranged that she also touches the water for a short distance at the stern at the point C. In this position the surface of the boat touching the water is very small and the resistance is accordingly reduced. It must be understood that in these figures the parts are not accurately to scale but are drawn so as to show the principles of working. The step is shown exaggerated for clearness.

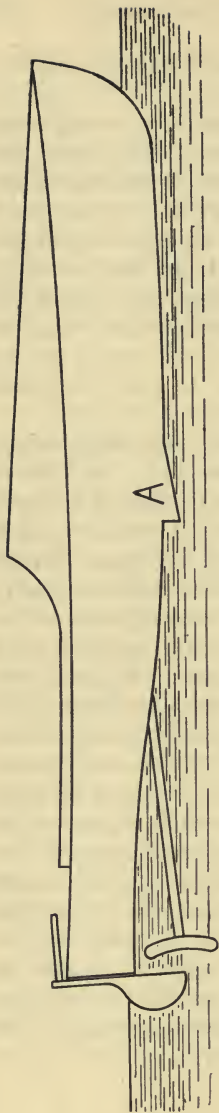


FIG. 9



FIG. 10

In this way a very much greater speed can be obtained than is possible if the whole boat is driven through the water, while at the same time the boat is kept quite useful in other ways. It is obvious that for such purposes as the coastal motor boats were used in the war, a boat which was quite unseaworthy would have been useless.

It will be seen from the above description that the skimming boat has no advantage over the ordinary type below a certain speed. Unless a considerable power is put into a small weight the boat will not lift on the plane, and therefore behaves as an ordinary boat. In this case, of course, any form of plane must be more or less a disadvantage, and therefore for moderate speeds it is better to stick to the ordinary arrangement.

It is not possible to say exactly what is the lowest speed at which it is possible to make a satisfactory skimming boat, but at present it appears that in a boat of, say, 30 to 40 ft. long there is no gain in speed by making it of this type unless it is to go over 20 knots. Below this, therefore, it is generally better to make the boat of the ordinary type, but above this there is a distinct gain in speed for a given power by making it skim.

It is difficult to tell what will be the development of the skimming type. It may be that it will be found that with experience the principle can be applied satisfactorily to slower boats than it is at present, and it is also possible that much larger boats may be built than have been yet. The largest boat so far made on this principle is about 70 ft. long.

CHAPTER VIII

EXAMPLES OF MOTOR BOATS IN PRACTICE

THE range over which motor boats are now made makes it quite impossible to describe or illustrate more than a few more or less typical examples. In fact, all we can do is to show enough to give some idea of the very great range they cover. The following are therefore selected for the purpose of showing this, but it must be quite understood not only that there are a great number of makers of most excellent repute, but also that each maker makes a considerable number of types of machinery as a rule, and further, that each boat builder is prepared to build boats for a great variety of purposes and of different proportions. In this respect the trade is quite different from the motor car trade. In the latter the variation of size between the smallest and largest is not very great, and the variation of type in each size is small. One 20 h.p. car is very much like another 20 h.p. car, and one 3 ton lorry very much like another 3 ton lorry. There are, of course, certain minor differences, but they are small. All the engines burn the same fuel and all weigh about the same amount per horse-power and run at somewhere near the same speed. Further, the variation in the cars themselves is very small and usually one particular type of engine is only used in one type of car.

It is, therefore, quite common for a maker of motor cars to make only one size and type of car with no variation in the engine or any other part except the body. A relatively small number of such types of car supplies the needs of the world.

In the case of the marine motor things are quite different. Here the range of power is from, say, 2 h.p. to 4,000. Besides this, engines of each horse-power have to be built of widely different types. They have to burn all sorts of different fuels, needing in some cases quite different construction of the whole engine. They may weigh anything from 6 lb. per horse-power to 300 lb. They may run at any revolutions per minute from 75 to 2,000.

Another point in which the motor boat trade varies very much from the car trade is that there is far greater variation in the number of cylinders used, and these are not proportionate to the power of the engine. In motor cars the large majority have either four or six cylinders and, generally speaking, the larger the car the more cylinders.

One and two cylinders are only used for motor cycles and a few very small cars, while only a few very large cars have eight or twelve. In the marine motors the variation is greater and, further, has little relation to the engine power. Practical engines of under 1,000 h.p. have been built for special purposes with twenty-four cylinders and, on the other hand, 3,000 h.p. engines with only four.

These variations are necessary to fulfil the very varying purposes for which marine motors are required.

It is, therefore, quite impossible to supply the needs of the public in the same manner as is done in the car trade, namely by a comparatively small number of standard types. Each engine maker, therefore, as a rule, makes a good many sizes and often makes a considerable variation of actual types.

With regard to the boats themselves the variation is still greater, and is, in fact, so infinite that it is impossible to give illustrations of many distinct types.

Motor boats may be used for pleasure, passenger, or cargo work ; may be built for fishing or other special trades, and each of these purposes may have to be provided for in any kind of water. Thus, they may be built for sea, lake, or river, and may either always work in deep water or have to go over shallows a few inches deep, or they may have to combine shallow draught with fair seaworthiness. They may be fast or slow, or may be auxiliary to sails. They may be used in hot or cold countries, or both. They may have to be worked by native labour. They may be built of wood, steel, or even concrete. The variations are therefore infinite, and to a very large extent each boat is designed for its special purpose and fitted with a suitable motor. So we may have the same motor used in quite different types of boat, one, perhaps, ten times the size of the other ; and we may have the same type of boat with different motors of different powers according to the speeds required and the fuel it is desired to burn.

Evinrude. Marine motors cover a very great range of size, as previously stated, and it is one of their great advantages that they can be made commercially in smaller sizes than is possible with steam engines. In the case of the latter, it is hardly practicable to get an engine and boiler of sufficiently substantial proportions to be a commercial article to weigh less than 3 or 4 cwt. Naturally, this very much limits the scope of their employment as it means that it is not possible to employ them in boats below a certain size and weight.

The petrol motor can, on the other hand, be made of very small size and weight and yet be a commercial article, capable of running for a long time and with little attention. Hence, the marine motor is not only displacing the steam engine but is being used very

largely for work which could not be done in practice by steam at all.

An interesting example, therefore, of what is, perhaps, the smallest size engine sold in any quantity is the "Evinrude," which is made as a complete unit combined with

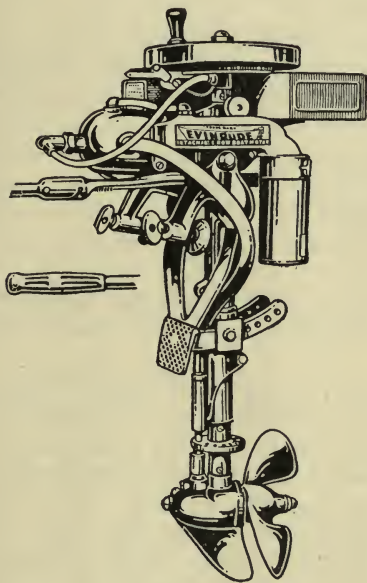


FIG. 11

the rudder, and so arranged that it can be clamped on to the stern of any ordinary rowing boat. This machine is shown in outline in Fig. 11. The unit is complete, with its petrol tank, silencer, motor, propeller, etc., and therefore requires no alteration to the boat of any kind whatever and takes no room inside it at all. The engine is set with the crank-shaft vertical, and drives

the propeller through bevel gearing, and the whole can swivel round the crank-shaft so to act as a rudder. The gearing runs in a case filled with grease. A single cylinder, $2\frac{5}{8}$ in. diameter by $2\frac{1}{2}$ in. stroke, is used, the engine working on the two-stroke cycle. At 800 revolutions per minute 2 h.p. is developed. The crank-shaft is $\frac{3}{4}$ in. diameter.

Reversing is effected by swinging the whole of the lower part containing the propeller round the rudder post till the propeller points forward instead of backwards. In order to do this a catch is released, and the drag of the gearing carries the whole of the lower part round a half turn. On the catch being again released it turns another half turn, and the boat goes ahead again. The weight of the complete unit is about 70 lb.

The large scope for a unit of this kind is obvious. It is sold at a low price and needs no work being done to the boat.

In the case of an engine of any kind being fitted to a boat not built for power there is usually a considerable amount of work to be done as a hole has to be bored through the stern post for the propeller to go through, and the stern post has generally to be strengthened to compensate for the weakening effect of the hole. Engine bearers have also to be fitted, and floor boards or seats often altered to allow for the room taken up by the motor. A special rudder has often to be made, allowing room for the propeller. All these items mean a good deal of expense.

With a detachable motor of the type shown above nothing need be done to an ordinary boat except simply clamp on the motor unit, start up and go. It can, if desired, be shifted from one boat to another, and can be removed from the boat and stored indoors in the dry

in the winter if desired. Fig. 12 shows an example of a boat with motor attached.

A larger type, having a cylinder $3\frac{1}{4}$ in. diameter by 3 in. stroke, is also made giving $3\frac{1}{2}$ h.p. and weighing 110 lb. Small as these engines are they will propel boats from 12 to 20 ft. long at 6 to 8 miles an hour, the speed, of course, depending on the weight of the boat and the size of the motor. This is a good deal faster than the same boats could be propelled for any distance by oars.

In addition to the type of motor unit described, the Evinrude Co. make small motors for placing inboard in the ordinary place. The smallest size of these has the same sized cylinder and power as the small sized rudder motor and weighs 45 lb. It stands about 16 in. high from the bottom of the flywheel to the top of the sparking plug, and is under 18 in. overall length, including the starting handle, and 12 in. wide. Obviously, this can be installed in a very small boat if built with a suitable stern for taking the propeller.

Owing to their very great convenience, cheapness, etc., these small engines have come into very considerable use.

Thornycroft. Among the firms who have been noted for many years for their steam boats but have since taken up the motor boats, are Messrs. J. I. Thornycroft & Co., Ltd., whose name is well known as pioneers in the matter of torpedo boats and high speed steam boats generally. Accordingly, perhaps the most interesting of their productions are the "coastal motor boats," which were used in the late war. These are really very small torpedo boats of very high speed.

In the early days of the steam torpedo boat the essential features of its construction were that it should be very small so that large numbers could be built at

moderate cost, and that it should have a speed greater than that of the large ships. Accordingly, the original torpedo boats were about 60 ft. long, and were soon followed by others about 90 ft. long. By fitting very special light machinery these boats were given a speed greater than that of the battleships they were intended to attack, the 60 ft. boats doing about 16 to 17 knots and the 90 ft. 20 to 22. The theory of their use was that being small, and carrying a very small crew, they could attack in numbers, and that it was of little matter if some were lost provided one or more attained their object of torpedoing a large ship. Gradually, however, the speed of the large ships increased, largely as the result of the adoption of the principles of the torpedo type machinery, and as it did so the speed of the torpedo craft had to be increased also. This necessitated their being much larger, and so the torpedo boat grew from 90 to 150 ft. long, and eventually became the "destroyer," which has now got to be from 250 to 300 ft. long and anything up to 40,000 h.p.

Excellent as these boats were, it is obvious that they are expensive and take a large crew, and they cannot, therefore, be built in the numbers in which smaller boats can be. Hence, they can hardly be used in the manner originally intended.

It was therefore felt that there was room for a small-sized torpedo boat which would fulfil the requirements of the original steam torpedo boats of thirty years ago. As the large ship now steams at some 30 knots, this meant a speed of 35 knots in a small boat. No such speed can be got with steam machinery of any practicable construction, but the racing motor boats had shown before the war that it could be got with motors.

Accordingly some boats were built which were 40 ft. long, 8 ft. 6 in. broad, and were fitted with a Thornycroft



FIG. 12

engine having twelve cylinders $5\frac{1}{4}$ in. by 7 in., specially designed for the work and intended to give 250 h.p. With these a speed of 35 knots was obtained or practically 41 statute miles an hour. These boats were built of wood of two skins, the inner running diagonally from the keel to the gunwale and the outer running horizontally. The timbers, or ribs, were steamed and bent to shape. The result was a boat of very strong and elastic construction, one which was well able to stand the very powerful machinery installed. For convenience of construction they were built upside down and turned over when finished.

These boats carried one torpedo, which was launched over the stern.

These boats were very successful, but it was desired to have still greater speed, and accordingly a new type was built 55 ft. long by 11 ft. beam and fitted with twin screws, each screw driven by one of the same engines as had been used in the 40 ft. boats. The power was therefore doubled and a speed of about 38 knots was obtained.

In later boats an improved engine, with cylinders $5\frac{3}{4}$ in. by 7 in., was used which gave about 450 h.p., that is 900 for the two engines, and with these speeds up to about 41 knots were obtained.

Fig. 13 shows one of these boats at full speed.

These later boats being bigger could carry more weight, and accordingly were armed with two torpedoes in place of one. In some cases one of the torpedoes was replaced with six depth charges for dealing with submarines.

This is a very interesting development of quite a special type of warship which would have been quite impossible with steam. This will be seen when it is considered that the speed of the original 60 ft. torpedo



By the courtesy of

FIG. 13

Messrs. Thornycroft & Co. Ltd.

boats was about 16 knots, and that the best speed ever got in a boat of this size was about 20 in place of the 40 with the motor. It would be quite impossible to put enough power into a boat with steam machinery substantial enough to stand service conditions for anything like 40 knots, and even if this power could be put in the fuel consumption would be so great that all the fuel would be burnt in such a short time that the boats would be quite useless. In fact the only warships afloat which were as fast as these little boats were the very largest and fastest of the destroyers, which were about six times as long and over thirty times the power, and these boats did just about the same speed, namely 40 to 41 knots.

These boats proved of great use in the later naval operations of the war, but it is hardly possible to give a detail of their performances here.

Naturally, the machinery for such very high speed boats has to be as light for its power as possible, and is therefore somewhat delicate and expensive. Accordingly, for ordinary work the firm make more substantial types. Fig. 14 shows one of the smaller sizes they make, which is of very simple and substantial type, having only two cylinders. These are $4\frac{1}{2}$ in. diameter by 6 in. stroke. This engine runs at 1,000 revolutions per minute and can be arranged to run either with petrol or paraffin. In the latter case a vaporizer, heated by the exhaust gas, is fitted, and this can be heated by a lamp before starting, or alternatively the engine can be started on petrol and run for a few minutes till the vaporizer is hot. With petrol 18 h.p. is obtained and with paraffin 15. A separate reversing gear is fitted, and the engine and reverse gear weigh $10\frac{1}{2}$ cwt.

Fig. 15 shows a standard type of cruising launch, 35 ft. long by 6 ft. 9 in. beam, which is representative

of a very large number which are being built for pleasure cruising. This boat is fitted with a four-cylinder motor having cylinders 4 in. diameter by $5\frac{1}{2}$ in. stroke, which gives 25 h.p. on petrol or 21 on paraffin at a speed of 1,000 revolutions per minute. This engine is fitted with a reverse gear as usual in small motors, but does

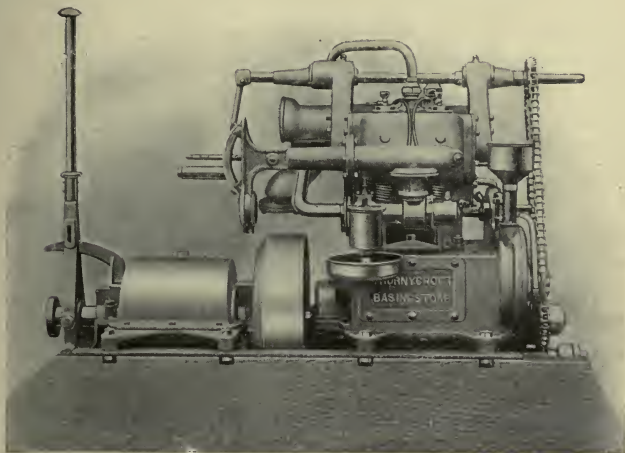


FIG. 14

not need starting by hand as it has an electric starter of the type usual in motor cars, the electric equipment also supplying electric light for the cabins. The speed obtained is 11 knots.

This boat is a very good instance of the advantages of the motor for small cruisers. In the first place the speed is distinctly higher than used to be usual in a steam boat of this size ; in fact, such a speed could only have been got by using machinery of very large size

for the boat and of somewhat delicate construction. The fuel consumption would have been very heavy and, therefore, the distance which could be run without taking in fuel very small. The room taken up would also have been so great that there would have been very little left for cabins, etc.

With a motor the room taken up is very small indeed, and in consequence there is a great deal of accommodation for the size of the boat. Forward there is a chain locker, then a forecastle large enough for two to sleep. Aft of this, a saloon with two comfortable settee berths, aft of which is a lavatory alongside the engine. Behind the engine room is a roomy open well for use in fine weather.

In fact, this boat has the speed and accommodation usual in a steam launch 50 ft. long or more.

Brooke. Another of the firms in this country who early took up the manufacture of marine motors and motor boats was Messrs. J. W. Brooke & Co., Ltd. This firm has constructed a variety of boats and engines of various kinds, including some very successful racing boats in the days before the war. Fig. 16 shows a small motor tug of a type much used by the Inland Water Transport in the war. She is 40 ft. long by 9 ft. beam, with a draft of 2 ft. 9 in., and has engines of 49 actual horse-power giving a speed of 9.4 knots. Fig. 17 shows a type of the moderate speed cruiser and gives a good idea of the accommodation which can be obtained in a small boat fitted with a motor of moderate power. This launch is 30 ft. long by 7 ft. 6 in. beam, and has a motor of $9\frac{1}{2}$ h.p., which gives her a speed of 6.61 knots, which would have been considered a good speed for a boat of this size and type with steam machinery.

The accommodation is as follows: W.C. forward, saloon (two sofa berths), galley with sliding hatch. The



By the courtesy of

FIG. 15

A CRUISING LAUNCH

Messrs. Thornycroft & Co., Ltd.

motor is under the forward deck but not enclosed aft, and is bulkheaded off from saloon and galley. There is a large well where two can sleep if necessary.

Fig. 18 shows a photo of the saloon which will give some idea of the type of accommodation which can be arranged in such a small boat with motor propulsion. With steam the engines and boilers would take up the best part of the boat. This boat is also a good example of how small a power is necessary in a motor boat if a really moderate speed only is desired.

Sterling. For reasons previously given the motor boat has had a far greater development in America than it has over here, and, further, petrol engines are commonly made of considerably greater power. In England the petrol motor has, so far, only been used to any great extent for the smaller powers where economy in the cost of fuel is not of great importance, and the larger models are usually made to burn paraffin. Really high speed boats, and those used for naval purposes, have, of course, had petrol engines of considerable power, but in peace time these are only made in very small numbers. Most people in this country are content with a speed of some 12 to 15 knots, or even a good deal less, in an ordinary cabin launch, and this can be got with relatively small power. In America there is a very much larger demand than there is here for pleasure launches combining cabin accommodation with a good deal higher speed than this and, therefore, very much more powerful engines are common than are usual here. These engines have to be relatively light and compact and are, therefore, run at fairly high speed, up to 1,500 revolutions per minute, but must be of sufficiently substantial construction to stand a considerable amount of hard work. Hence, the extreme light type of engine, as used in the aeroplanes and racing boats, is inadmissible. Petrol

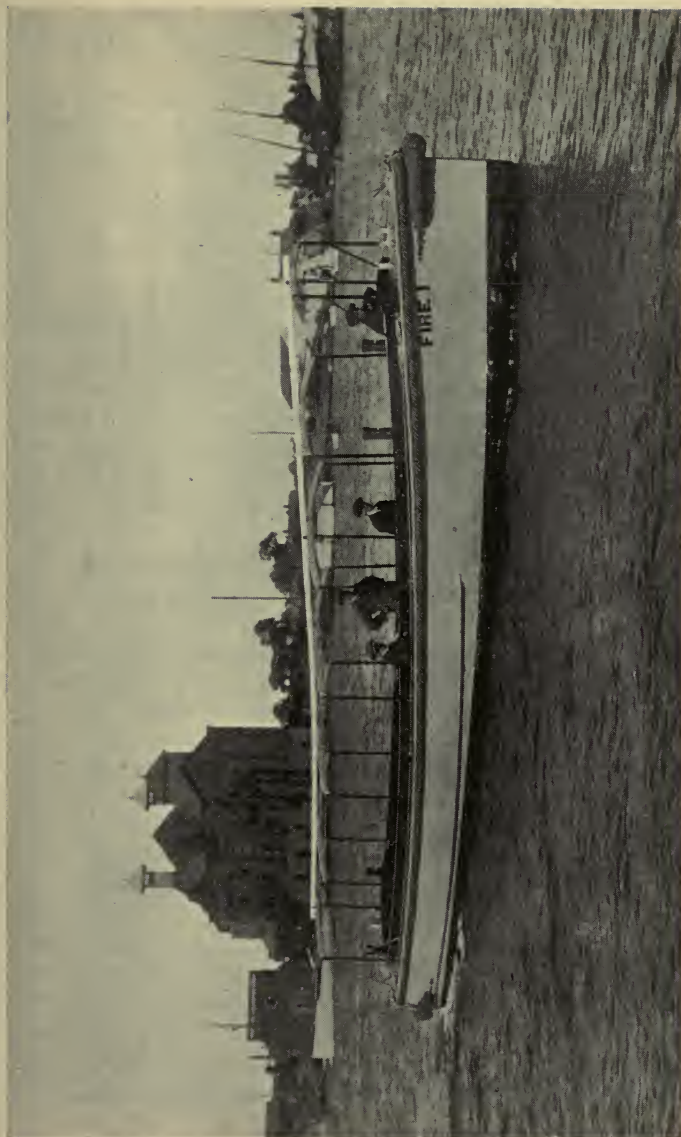


FIG. 16

is used as fuel as it is the most convenient and the expense is not considered serious enough to prevent the use of this. Petrol is cheaper in the U.S.A. than here, and presumably money more plentiful.

The following illustrations of a few of the productions of the Sterling Engine Co. of America are therefore of interest.

Fig. 19 shows a cruiser of this type, 45 ft. long by 11 ft. beam, having a speed of $21\frac{1}{4}$ knots ($24\frac{1}{2}$ statute miles). This boat is not in any way a racing machine, as can be seen from the photo, but is a boat with a considerable amount of accommodation. Yet the speed is quite high. In order to get this speed two engines are installed, driving twin screws, each engine having six cylinders $5\frac{1}{2}$ in. diameter by $6\frac{3}{4}$ in. stroke. The total power is nearly 300 h.p.

A larger boat of the same general type is shown in Fig. 20. This is 66 ft. long by 12 ft. beam, and has a speed of 21 knots (24 statute miles). Twin screws are used, each engine developing 200 h.p. and having eight cylinders $5\frac{1}{2}$ in. diameter by $6\frac{3}{4}$ in. stroke. This boat, again, is a substantial sea-going vessel, having a very considerable amount of accommodation yet having a very high speed for a boat which is not of the real high speed or racing class.

In order to get such speeds it is obviously necessary to have considerable power, and accordingly the Sterling motors are standardized in powers up to 450 h.p.

Fig. 21 shows side view of one of the latest pattern engines, giving 300 h.p. at 1,500 to 1,600 revolutions per minute, having eight cylinders $5\frac{3}{4}$ in. diameter by $6\frac{3}{4}$ in. stroke. This engine has the valves in the cylinder head, and the latter is detachable. There are two inlet and two exhaust valves to each cylinder, driven by push rods from cam-shafts in the crank case. An

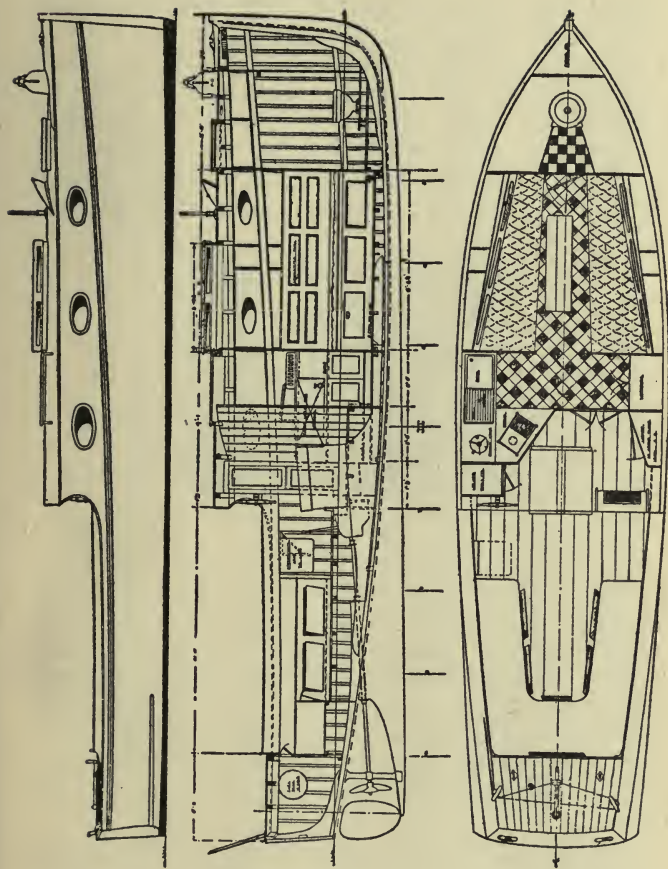


FIG. 17

important feature of the Sterling engines is that the reversing gear is not a separate unit which has to be erected in the boat in line with the engine, but is built as one unit with it, while the flywheel is cased in so that it cannot throw water about. An electric starter is provided, and there is also a dynamo for charging the batteries for this and the electric light. The cylinders are cast in pairs, hence the same cylinder casting can be used for engines having four, six or eight cylinders,



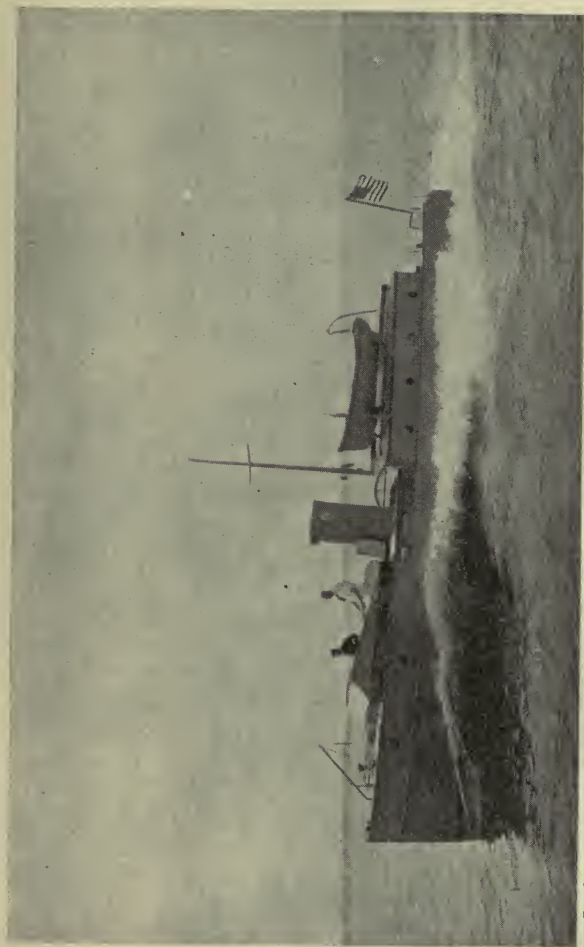
FIG. 18

the corresponding horse-power being 150, 225, and 300 h.p.

It is interesting to note that the Sterling Engine Co. make a considerable number of eight-cylinder engines, and in all cases place the eight cylinders in line. This differs from general European practice where, as a rule, engines with more than six cylinders have had them placed diagonally with two cylinders on to one crank.

Various sized engines are made, ranging from a 15 h.p. two cylinder to a 300 h.p. eight cylinder, having cylinders $6\frac{3}{4}$ in. by 9 in., and developing its power at the moderate speed of 1,000 revolutions per minute.

Sterling engines have been used for high speed and



By the courtesy of

FIG. 19

A CRUISER

The Sterling Engine Co., U.S.A.

racing boats. Thus, the 20 ft. launch, *Miss Detroit II*, in August, 1917, attained a speed of 59.43 miles an hour ($50\frac{1}{2}$ knots) for 6 miles, and maintained 56.5 miles an hour (47 knots) for 30 minutes. This speed stood as a record for some years. The output of the Sterling Engine Co. is now about 800 engines a year, the predominating type being the six cylinder. It is not possible to get the total horse-power turned out in a year, but it seems probable that the average horse-power of the engine is at least 150, in which case the total for the year will be over 120,000 h.p. That is to say, that the power of the petrol engines turned out by this firm in a year is equal to that of most of the large marine engine builders in this country.

Vickers-Petters. All the examples of motors so far described have been of the type in which the fuel is mixed with the air before the latter is taken into the cylinder. Further, they are all essentially developed from the type of engine used in the motor car, this, of course, having been modified as necessary to fit it for marine work.

As previously explained, however, there are marine motors which have essentially developed from the adoption of principles which have been worked out in stationary engine practice, and these are required to burn much cheaper fuel than petrol or paraffin.

We have seen that there are great difficulties in vaporizing such oils before they go into the cylinder, and that they are, therefore, sprayed in after air alone has been compressed, and, further, we have seen that the engines which work on this principle are divided into the "Diesel" and "hot bulb" engines.

Pioneers of the latter type were Messrs. Petters, Ltd., now Messrs. Vickers-Petters, Ltd., The principal of working of their engine will be seen from Fig. 28. We



FIG. 20

have seen that if air alone is compressed, as in the Diesel engine, so that oil will fire when sprayed in, the compression pressure has to be so high as to be a serious disadvantage, and we have also seen that unless the cylinder and combustion chamber of a motor were water-jacketed they would get red-hot from the heat of the explosions. Further, if the combustion chamber,

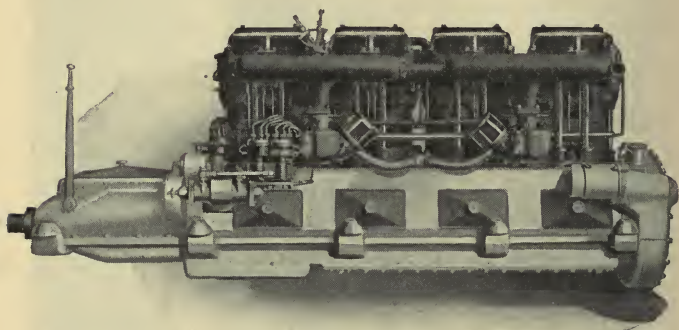


FIG. 21

or any part of it, is hot the compression pressure at which the oil will fire is very much reduced.

In the illustration (Fig. 22) it will be seen that the cylinder and greater part of the combustion chamber is water-jacketed in the usual way, but that a small part at the top is left unjacketed. Accordingly, when the engine is working this part gets hot. Air alone is compressed, and just about the top of the stroke oil is sprayed against the hot part and instantly evaporates and burns.

The general action of the engine is the usual two-stroke cycle, as previously described, in which the crank case is used as the charging chamber. This is, of course,

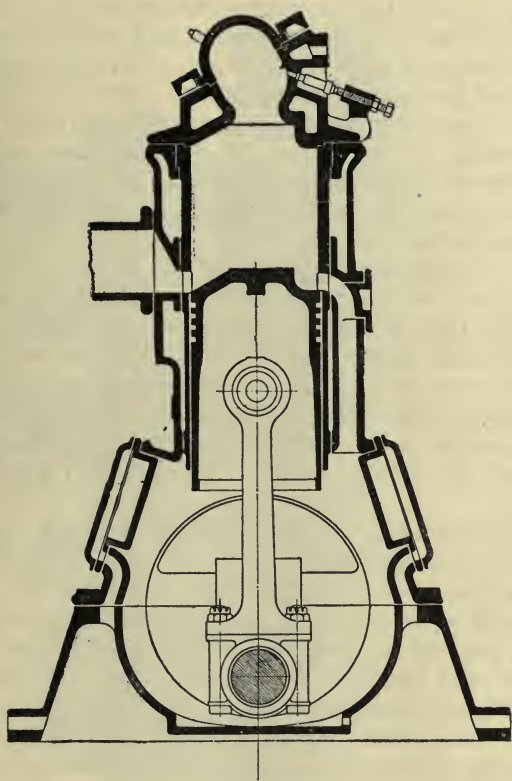


FIG. 22

the simplest engine it is possible to build, as it has no valves or charging pump.

It is obvious that an engine working on the principle described cannot be started when cold, as the oil would not vaporize or fire. Accordingly, some means must be provided for heating the engine to start. To heat the bulb a special burner using paraffin is provided, which will enable the engine to be started in one minute. Directly the engine starts the burner can be extinguished as the explosions of the oil keep the bulb hot enough for the engine to work.

As an alternative to the above Messrs. Vickers-Petters supply an electric torch which is heated by current supplied from a small accumulator. This torch serves to fire the oil till the bulb gets hot, when it is withdrawn from the heat of the combustion chamber and the current is switched off. The accumulators are kept charged by a generator driven from the engine, and this set can be used for lighting two or three lights in the engine room.

Fig. 23 shows a six-cylinder engine capable of giving 500 h.p. when running at the moderate speed of 250 revolutions per minute. The cylinders are 16 in. diameter by 18 in. stroke, and the weight 630 cwt. In these engines the propeller is coupled direct on to the engine, and the latter is capable of being reversed and is started in either direction as required. As it works on the two-stroke cycle it will run in either direction, and there are no valves to be altered in setting to make it go astern.

For starting in either direction compressed air is used. This is stored in vessels at a pressure of 200 lb. per square inch, and is supplied by an auxiliary air compressor set. One advantage of the hot bulb type of engine is that the starting air need not be of such a high

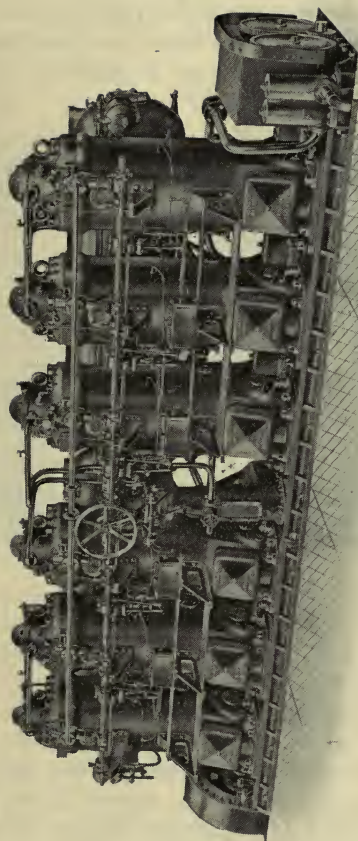


FIG. 23

(Vickers-Peeters)

pressure as in the case of the Diesel, as the compression pressure is lower. It is obviously necessary that the compressed air used for starting should be capable of overcoming the compression in the cylinder, and therefore the lower the latter the lower the pressure of air necessary for starting. The air is admitted into the

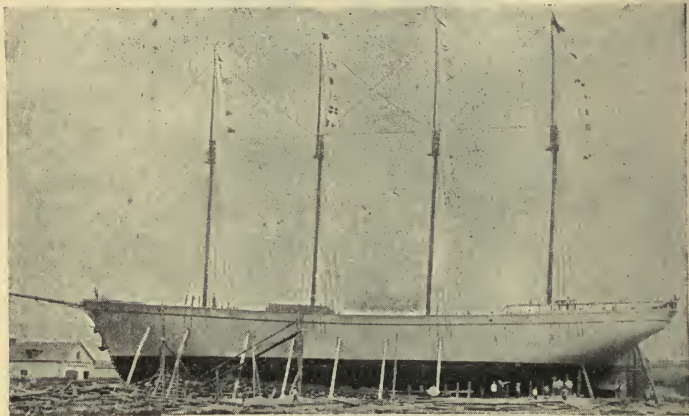


FIG. 24

cylinders as required by mechanically-operated valves, and as soon as the engine is started can be cut off.

These engines are made in various sizes, from a single cylinder 10 h.p. up to the 500 h.p. described.

Fig. 24 shows an interesting example of a sailing ship with auxiliary machinery. This vessel is 218 ft. long by 35 ft. 6 in. beam, and has a 220 h.p. engine which gives her a speed of 6 knots. As the ship is 2,000 tons and the weight of the engine only 15 tons, the latter will make practically no difference to her sailing or cargo-carrying

capacity, while it enables her to progress in calm weather and to get in and out of harbour in a way that she could not do by sail only.

As the oil does not have to be vaporized before going into the cylinder almost any kind of oil, from paraffin to

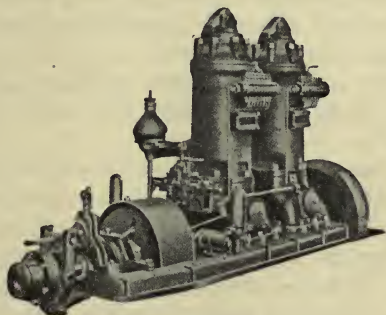


FIG. 25

tar oil, can be used in the engine. The consumption is about $\cdot 5$ lb. per horse-power per hour.

The Grei engine is the result of Norwegian development of the two-cycle hot bulb type of engine, and has been manufactured for twenty years. Combustion space is formed by the cylinder head and hot bulb, which latter is water-cooled in the neighbourhood of the injection valve. Starting is performed either electrically or by means of a blow lamp, thus the cylinder pressures are kept very low whilst the guaranteed fuel consumption is only $\cdot 49$ lb. of crude oil per b.h.p. per hour.

The patent injection valve controls the temperature of the hot bulb and allows the engine to be thrown on to full load immediately after running many hours unloaded at a reduced speed of revolution.

The engines are made in sizes from 4 b.h.p. to 540 b.h.p. with single, two, and four cylinders. Engines of 30 to 60 b.h.p. are made in both single and two cylinder types.

Four cylinder engines are direct reversible by means of compressed air without the use of a compressor and other engines have reversible propellers or can be supplied with spur-driven reversing gear.

All engines are built to Lloyds specification and can be fitted with deck control and compressed air starting arrangements.

The compressed air tank receives its charge from the engine cylinder whilst the engine is on full load.

Fig. 25 illustrates one of the two-cylinder engines having cylinders $10\frac{1}{2}$ in. diameter and $12\frac{1}{4}$ in. stroke developing 70 b.h.p. at 350 revolutions per minute. This engine is fitted with reversible propeller, clutch, and centrifugal governor for controlling the speed of the engines whilst same is under way.

Doxford. As has been mentioned, there are some practical difficulties in producing oil engines developing over a certain power for each cylinder. This is especially the case where it is desired to keep the engine speed low. For any given sized cylinder the power which can be obtained increases the faster the engine is run. There are, however, great objections to running very fast large engines used for such work as cargo ships, as the faster an engine runs the greater the wear. It is absolutely necessary that the oil engine shall be as reliable and as durable as the steam engine, if it is to compete with the latter in commercial work, and therefore the speed has to be kept about the same as that of the ordinary steam engine used in a similar class of work, that is to say, under 100 revolutions per minute. This necessarily entails large cylinders.

Accordingly, the engine shown in Fig. 26, which is made by Messrs. William Doxford & Sons, Sunderland, is very interesting as it has only four cylinders and yet develops 2,700 b.h.p., that is to say, 675 h.p. per cylinder, at only 77 revolutions per minute.

In order to get this result several considerable alterations are made in the ordinary design.

The engine works on the two-stroke principle, but has two pistons in each cylinder working in opposite directions. That is to say, that the cylinder is simply a straight tube with a piston coming out of each end. These pistons are connected to cranks in such a way that the top piston is going up when the bottom piston is going down. The two first move towards each other, and then away from each other. The result of this is that twice as much power is got from each cylinder as would be the case if each cylinder had only one piston. To get the same power from cylinders of the same size and of ordinary construction, other things being equal, therefore twice as many cylinders would be required, and this would entail having twice as many valves, etc.

There are some other very distinct advantages in the principle of the opposed piston for very large powers. One of these is that the strain on the framing of the engine is very much less. In the ordinary engine there is an upward pressure on the framing equal to the downward push of the piston, and this pressure gets very large indeed in big engines. Where there are two pistons pushing in opposite directions both these pressures are taken straight to the crank-shaft and used for turning the crank, and therefore there is no vertical pressure on the framing at all.

The engine, as illustrated, has four cylinders $22\frac{3}{4}$ in. diameter, the stroke of each piston being $45\frac{1}{2}$ in. As mentioned, it works on the two-stroke cycle, the air

for scavenging being supplied from a separate air pump in the centre of the engine. In this case the exhaust ports are at the top of the cylinder and are uncovered by the top piston at the end of the stroke, while the inlet ports are at the bottom and are uncovered by the bottom piston. Thus the scavenging air comes in at one end of the cylinder while the exhaust goes out at the other, and the cylinder is very thoroughly filled with pure air.

The fuel used is, of course, fuel oil, and is sprayed into the cylinder between the pistons at the end of the inward stroke. The pressure used for spraying in the oil is very high, nearly 10,000 lb. per square inch, and the oil is supplied by suitable pumps through the necessary valve in the walls of the cylinders. In order to guard against any possibility of breakdown these pumps are in duplicate.

In a small engine the piston is kept quite cool enough by contact with the cylinder, which is, of course, water-cooled, as no part of the piston is very far from the cylinder walls, but in an engine of this size it is necessary not only to cool the cylinders but also the pistons, as otherwise the centre of the piston would get red-hot and the expansion of the whole piston would cause trouble. Water is therefore circulated through the pistons by flexible pipes. A special feature in this case is that the centre of the piston consists of a forged steel block, which is allowed to get hot to assist in the combustion of the fuel. By this arrangement the air does not need to be compressed to such a high pressure to ensure the fuel burning properly when it is injected, and the engine therefore works at a compression pressure of 300 lb. per square inch.

Fresh water is used for cooling the cylinders and pistons in order to avoid possible corrosion or deposit

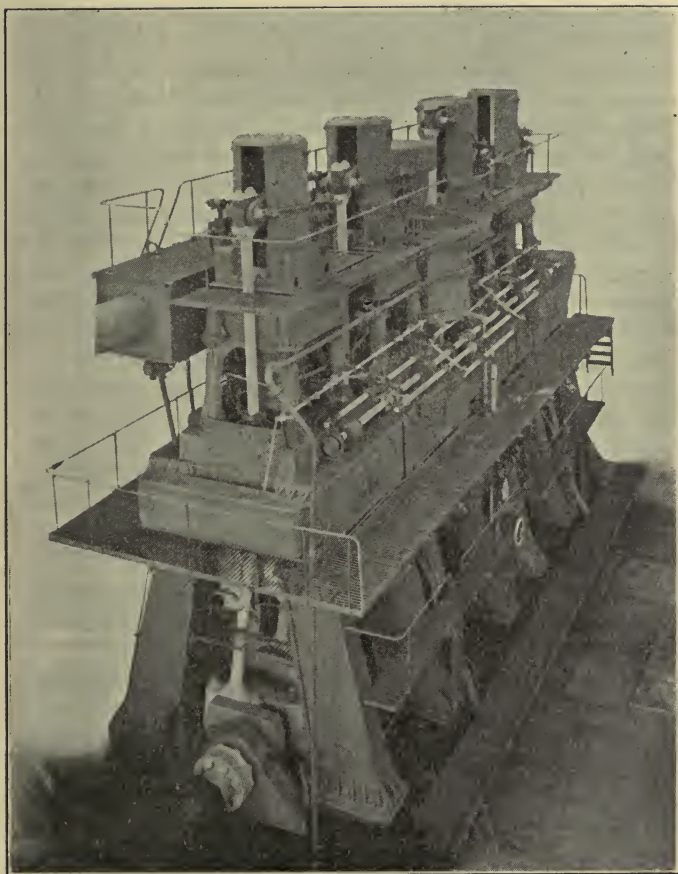


FIG. 26

through the use of salt water. The circulating water is cooled by circulating it through a cooler cooled by the sea water.

The starting and reversing of the engine is done by compressed air. This is supplied by a small separate engine driving an air compressor. The fuel valves and the valves for admitting the compressed air for starting are all driven by a cam-shaft along the front of the engine. In order to reverse, the levers which work these valves are lifted off the cams and the shaft slid endways till the reverse cams come under the levers, which are then allowed to again touch the shaft. The compressed air is turned on and the engine starts. After the first revolution the engine fires and the compressed air can be cut off. The engine can be run down to sixteen revolutions per minute when firing on oil. With suitable oil the consumption is 0.42 lb. per brake horse-power per hour.

The Frontispiece shows the motor ship *Yngaren* under way. She is the first of four 10,000 ton standard ships, and is fitted with one of the engines described.

This photo, and Fig. 26, give a very clear idea of the size to which the oil motor has now grown and of its scope in large vessels.

The oil engine began as a very small unit, only developing a few horse-power and capable of being easily started by hand. The cylinder was only a few inches diameter. An idea of the size of the engine described here can be got from the ladders, hand rails, etc., and it will easily be seen that it has developed into a very large piece of engineering, while the carrying capacity of the ship speaks for itself.

The weight of this engine complete aboard ship is 530 tons, which again gives some idea of its size. The weight of a triple expansion set of steam machinery of

the type usually put into vessels of this description is about 660 tons, the saving of weight in the case of the motor being, therefore, 130 tons or about 20 per cent. This allows, of course, 130 tons more cargo being carried. In addition to this the consumption of fuel over weeks continuous trial at full power averaged $12\frac{1}{2}$ tons per day, while it is not likely that the consumption of fuel in a steam engine of ordinary construction would have been much less than three times that, even with the most modern arrangements. The saving in fuel burnt would, therefore, be at least 20 tons a day at full power. On a really long voyage of, say, forty days this amounts to 800 tons. The actual saving in weight of the machinery and fuel together is, therefore, about 930 tons, which is a very material addition to the carrying power of the ship, being in fact in the neighbourhood of 10 per cent.

With regard to the space taken up, the length occupied by the motor is nearly as great as that taken by the steam machinery. Whereas the boilers take up the whole width of the ship, however, the motor does not take up anything like the full width. There is, therefore, a slight saving in length and a considerable saving in width.

Altogether, the comparison of steam and motor is extremely favourable to the motor and suggests great possibilities for the future.

CHAPTER IX

SCOPE AND FUTURE OF THE MOTOR BOAT

It is very difficult to make any forecast of the future scope of the motor boat, mainly because it appears so very large. It is, however, interesting to consider some possibilities. In the first place, it is quite within the bounds of probability that it may not be so very many years before the internal combustion motor completely replaces the steam engine at sea. At present there are difficulties in making these engines over a certain power, but it is probable that these will be overcome. One of the main difficulties is that as the size of the cylinder is increased the difficulties due to expansion and contraction increase, and from these and other causes it is not considered desirable to make the cylinders at present over a certain size. This limits the power which can be obtained from one cylinder. There are many objections to having a very large number of cylinders, and this limits the power which can practically be used.

This is a usual position in any kind of engineering, and at any particular time there is a limit to size or power in any machine beyond which engineers will not care to go. Such limits are, however, only temporary, and with greater experience and better materials engineers are constantly enlarging their limits. It is usually not desirable to make any very great step at once as this often means failure, and progress is generally most rapid if taken in a series of small steps. As an instance of this the *Great Eastern* steam ship was a complete failure owing to her size. Yet ships some four times as big are now quite successful owing to the

greater experience there has been since her day in construction.

Even in steam engines there is a limit to the power which engineers would care to undertake in a single unit. The steam engine is, however, a machine in which there has been far more experience than the oil engine, and it is probably largely for this reason that engineers are prepared to build steam engines of far greater power than oil engines.

Progress in the internal combustion engine has, however, been very rapid. This is true both of the light type using petrol and of the heavy type burning the heavier oils.

Taking the former type first, it is not many years ago that a high speed petrol engine of over 50 h.p. could not be trusted to run for an hour without breaking down, and in the early days of the racing of motor boats it was quite a common thing for a relatively low-powered boat to win because all the higher-powered boats broke down.

Now there are individual engines of 900 h.p. in use which are quite capable of running for any reasonable time without risk of breakdown. Further, these engines are lighter per horse-power than were the older engines of far less power.

Similarly, the early engines of the slower running and heavier type, using heavy oil, were of a very low power, and it was a long time before they could be got to give anything like 100 h.p. satisfactorily. Gradually the possible power rose till now there are satisfactory engines of over 4,000 h.p. in actual commercial use.

In both the petrol engine and the heavy oil engine the progress has become more rapid as the size in use increased. Whether this will be so in the future remains to be seen.

At present the limit of practicable power for an engine with a reasonable number of cylinders appears to be somewhere about 4,000 h.p. Two such engines driving twin screws would therefore give 8,000 h.p., and there does not seem any great reason why three or four screws should not be used, as is often done when steam turbines are used. This would give 12,000 and 16,000 h.p. respectively.

Now the power of the very fast Atlantic liners ranges up to some 70,000 h.p., while some of the very fast warships have double this. It will be seen that it will take a good deal of development for the I.C. engine to reach these powers. Nevertheless, there is no reason why it should not be done in time.

At the same time, the number of ships with more than 10,000 h.p. is a very small proportion of the total, and therefore it is already practicable to fit the large majority of even the large steamers with I.C. engines.

The great advantages of the I.C. engine for large ships are : First, there is a reduction in the weight and space occupied. Second, there is a saving in fuel consumption. Third, there is a saving in labour.

The first means that a ship of a given size can carry more cargo, and therefore earn more money, or alternatively earn the same money at lower freight rates.

The second has largely the same effect. Not only has less fuel to be paid for but also less has to be carried for a given distance run, and therefore again there is more available space for cargo.

The third is becoming increasingly important with the rise in the cost of labour. In a steam boat burning coal a very large amount of fuel has to be got from the bunkers into the stokehold and fed into the boiler fires. It has so far not been found practicable to handle this coal by mechanical conveyors and mechanical stokers,

as is done on shore, and therefore a great many coal trimmers and stokers have to be carried. In some of the powerful steamers these have amounted to several hundred men. These men have not only to be paid but have also to be housed and fed on board, and therefore take up a considerable amount of room. It is partly to save this labour that a good many steamers have been fitted to burn oil. By this means most of the stokers are dispensed with as the oil is pumped into the furnaces.

If oil is to be used at all, however, it is fairly obvious that it should be used in an I.C. engine, as the consumption of this type is only about half as much as a steam engine burning oil. Further, the weight and space taken up is reduced on account of the absence of the boilers.

Naturally, ship owners are desirous of being quite sure that the I.C. engine is going to work satisfactorily before using it on too large a scale, and it is quite impossible to tell accurately what defects may develop in new types of machinery until it has been in use for some time.

With greater experience, however, confidence is being rapidly gained, and therefore the use of the I.C. motor in large ships may be expected to extend rapidly.

With a general adoption of motor ships freights should be reduced, and this will have a general effect on trade, for the one necessity for good trade is cheap transport. It will enable goods to be brought at cheaper rates from places where they can be produced cheaply, and this may lead to some curious results. For instance, there is plenty of coal in the world nearer the surface than it is in England, and therefore cheaper to work, and it is within the bounds of possibility if our miners persist in their present attitude that we may literally see "coals

brought to Newcastle," or, at all events, imported into many parts of England by oil-driven cargo ships, while our own coal remains undeveloped.

It is, however, in the smaller sizes that the effects of the introduction of the motor boat will have the greatest effect. In the larger ships steam has, after all, performed the work required, though we may expect the motor to perform the same work better. In the small sizes, however, the motor can be used for a great many purposes for which steam has never been used at all.

This will have the greatest effect in the very small boats. Here steam has only been used to a moderate extent, and for many purposes does not fulfil requirements. On the other hand, a motor can be fitted satisfactorily even to the smallest rowing boat.

The result is that all work performed by rowing boats can be done at a higher speed and with less labour by motor boat, and at very small cost. Now, there are a very large number of rowing boats in use all round the coast which are used for fishing and other purposes, and it may be taken for granted that a very large proportion of them will very soon be driven by motors. This will soon lead to a large increase in the number of boats for it will lead to cheaper production, and this means increase in demand. Thus, where four men owned and worked a boat they will own two motor boats, and each motor boat will do probably twice the work. This means both cheaper production and also higher earnings for the men.

In addition, the motor will make the sailing boat more useful. Sails are the cheapest form of power available as long as there is any wind. Calms, however, make sails uncertain, and this uncertainty is often fatal to their use.

Steam has been tried as an auxiliary to sails, but it

is generally impracticable to put the machinery into the space available. With the motor there is no difficulty. The space taken up by both machinery and fuel is only a fraction of that of steam and, in fact, makes practically no difference in the space available for other purposes.

The sailing boat may, therefore, be given a considerable extended lease of life by being fitted with a motor capable of driving her at quite a slow speed simply for use when there is no wind. Even now there are a very great number of sailing boats in commercial use, and it is quite possible their number may extend.

For pleasure craft, of course, there is also a very large field, and we may expect the motor not only to replace steam but also to be used to a far greater extent, especially in the really small craft, than steam ever would have been. As the space taken up by the motor is so very small a much smaller and cheaper boat can be used for a given amount of accommodation, and this will open the possibilities of yachting to many who would never have been able to afford a steamer.

The motor boat may have a very distinct effect on the development of distant lands. Transport is always the difficulty of development here, and with the existing steamships it is not worth while to make calls at places where the amount of freight is only small. In fact, for these purposes steam has very distinct limitations, one being that a small steam boat will only carry fuel for a relatively short distance. The motor boat has enormous advantages in this and other respects.

There are many out-of-the-way parts of the world, therefore, where it would be practicable to collect produce by motor boats on a small scale in a way which has been quite impracticable hitherto. This may lead to the opening up of a great many new parts of the world.

In fact, the introduction of the motor boat may lead to very great changes indeed, possibly nearly as great as those produced by the introduction of the motor car. It will have a very strong tendency to put the small boat on a nearer level to the large one as regards economy of working. There are many industries which are best carried on in a small way and on a small scale by numerous different people working individually, provided motive power can be obtained at a reasonable price. The motor will supply this, and we may expect, therefore, to see a considerable increase in these small industries. This may have very great social effects. In fact, the development of transport on the sea may follow the same lines which it has done on the land. Here, until the advent of the motor car, the sole means of rapid transit was the railway, and if it did not pay the railway company to run a train rapid travel was impossible. This inevitably concentrated travel to certain large centres. With the motor car, motor bus, and motor lorry, all this changed, and small quantities of either passengers or goods can be conveyed rapidly in any direction.

It has only been possible in the above to make a few suggestions as to the possible results of the general introduction of the motor boat ; and it is quite probable that in a very short time its effects will be even greater than the most sanguine enthusiast expects. It is pretty certain that no one in the least foresaw the possibilities of the motor car, or had the least anticipation that one maker would now be turning out over 1,000,000 cars a year, and that its advent would change the countryside in the way it is doing. Yet, in one way the motor boat has an advantage over the motor car, for the latter can only go where there are some sort of roads while the motor boat can go wherever there is water, and a

great part of the area of the globe is covered with water, while there are innumerable rivers navigable to shallow draught craft all over the world.

With regard to the commercial possibilities in the manufacture of marine motors it is impossible to give any except the most general forecast. There is little doubt that in the future the development will be enormous.

Further, this development will take place along two very definite lines. There are two very distinct ways of producing such machines as engines. The first is to make each one individually, every part being machined to a drawing given to the machinist, and the various parts fitted together by hand. The second is to make all parts to gauges in automatic machines so that they go together without any fitting at all.

Naturally, the latter method entails a very great expense in machinery and gauges before there is any output at all, but once the machinery, etc., is set up the work can be produced a great deal cheaper than by the method of building each part individually.

In fact, these methods of production may be compared to writing with a typewriter and printing. Setting up type for printing is an expensive process, but once the type is set up the work can be produced very cheap. Thus, if only one or two copies of a document are required they can be typed by hand cheaper than they can be printed, but if several thousand are required it is far cheaper to set up type and print them.

Further, the greater the number of copies are required the cheaper they can be printed, as the cost of setting up the type is spread over a great number of copies.

The same applies to manufacturing. Hence the method by which motors are produced, and the price

they can be produced for, is simply a matter of the number required.

It is mainly because of the very large number of cars which can be built to standard patterns in America that the American car is so wonderfully cheap. Quite apart from Ford, whose car is a thing to itself, there are several makers in America whose output is over 100,000 cars a year all of one standard pattern, and it is safe for them to put in hand these huge numbers owing to the fact that they have a large market secured by a heavy import duty against outsiders. The result is that excellent cars of ordinary design, with three speeds, electric light, five-seated bodies, etc., etc., are sold in America at prices from £125 upwards.

These huge productions are possible in the car trade because a very few sizes of cars will fulfil the requirements of all buyers.

In the case of marine motors things are very different. Boats and ships vary enormously in size, and are used for very different purposes. In motor cars the sizes of engine in practical use range from 2 h.p. in the motor bicycle to 50 h.p. in a large car ; the number of engines over this power being a negligible proportion of the whole. All the engines run somewhere near the same speed, all burn the same fuel, all are somewhere near the same weight per horse-power.

In marine work the power required ranges from 2 h.p. to many thousands. The engine speed varies from 70 revolutions per minute to 2,000. Fuel may be petrol, paraffin, or fuel oil. In some extreme lightness is required for high speed, in others extreme durability almost regardless of weight.

It is obvious that under these circumstances the number of types must be enormously greater than the types of cars, and it is not likely for some time to come

that any maker will be able to have a large output confining himself to one pattern of engine, like the car maker.

Really large engines will, of course, be made in small numbers and, of course, made individually. In the case of the very small engines, on the other hand, the numbers will obviously justify repetition methods, and doubtless certain parts can be made interchangeable with car engines, and therefore produced in large numbers. Where the dividing line will come it is impossible to say.

In the small and medium-sized engines, however, our makers may be at a considerable disadvantage as compared with the Americans. The U.S.A. is a combination of some forty states having no import duties between these states but a practically prohibitive duty on such articles as marine motors coming in from outside. The American has, therefore, the whole of the market of a large number of states practically secured to him, while as there is no import duty on goods coming here he has ours in addition. Obviously, the market in the U.S.A. and England added together are far greater than that of England alone, and therefore the American manufacturer can sell and manufacture in far greater quantities than the English one. This means *prima facie* very much cheaper production, and cheaper production gives him, again, a great advantage in exporting to other parts of the world.

There can be little doubt that the English makers will be able to hold their own in all cases where this effect of the import duties does not have any effect, as, for instance, in the large engines which are made individually. Here good engineering design and construction is the main deciding factor. There is little doubt also that in the matter of design and absolute quality they will hold their own in the smaller sizes.

Whether it will be possible to produce the smaller sizes here at a price which will compete with the Americans, who have the above advantages, remains to be seen.

The matter is of great importance, for the production of small engines is becoming one of the most important of the engineering industries owing to the very great numbers in which they are made. It is seldom realized that the output of the makers of small engines often represents a total horse-power greater than most of the makers of large ones. The horse-power of the Fords produced totals something well over 20,000,000 h.p. a year, and this is probably far larger than the horse-power produced by any maker of large engines. This is, of course, very exceptional, but there are several other makers of small motor car engines whose yearly output is from 1,000,000 to 5,000,000 h.p., an amount which is a very large output for a maker of large engines.

The same may very likely happen in the motor boat, and it is quite likely that in the future the total output of the makers of small engines may be greater than that of the makers of large ones.

Possibilities of the Motor Warship. It is to be hoped that we may not have to use our warships for a very long time yet, but there is little doubt that war will not be extinct for some ages, and therefore preparations will have to be made. In the naval part of these the motor ship will undoubtedly play an increasing part. In the first place the submarine is capable of a great deal of development, and it is likely that a very large part of future fleets will, at all events, be submersible, and in this case be propelled by oil motors.

There is also the possibility of extremely high speeds being obtained in suitable craft. We have seen that in the smaller sizes the possible speed in practical boats

suitable for war is about double that possible with steam. At present there are difficulties in making this very light type of machinery over some 40 h.p. per cylinder, forty-eight cylinders being used to get 1,800 h.p. There is little doubt, however, that these difficulties will be got over, and we may expect that such machinery will be available for very much larger craft than at present. In this case there is no reason why, in the larger sizes, speeds about double what are now possible should not be obtained, that is to say, speeds of some 60 knots or more. The effect of this on naval warfare would be considerable.

Conclusion. Altogether, it is quite impossible to foresee the possibilities of the motor ship and boat, both for commercial and naval purposes, and all that can be said is that they are quite enormous, and that the general adoption of the motor may result in a revolution of transport on the sea second only to the change from sail to steam.

INDEX

- ADVANTAGES of motor boats, 37
- American motors, 82
- manufacturers, their advantages, 111
- Auxiliary sailing ship with Vickers-Petter engine, 95
- — ships, possibilities of, 106
- “ BROOKE ” motors, 80
- CARBURETTOR for petrol, 47
- Cargo, carrying power of, 101
- Coastal motor boats, 73
- — —, weight of engines of, 60
- Compression, advantages of, 24
- , limits of, 25
- Cooling of cylinders, 16
- Cruisers, “ Brooke,” 80
- , “ Sterling,” 82
- , “ Thornycroft,” 78
- Cylinders, number of, 20
- “ DIESEL ” engines, 24
- — *v.* gas mixture, 34
- “ Destroyers,” size and power of, 10, 74
- “ Doxford ” engines, 96
- ENGINE speed and weight, 56
- “ Evinrude ” motor, 70
- Explosion pressures, 14
- FOUR-STROKE cycle, 11
- — — *v.* two-stroke, 32
- Fuel, consumption of in different engines, 39
- Fuel oil, properties and use of, 48
- Fuels, comparison of, 51
- , different types of, 45
- GAS mixture *v.* injection engines, 34
- Gears, reversing, 29
- “ Great Eastern ” steamship, 102
- “ Grei ” engines, 95
- “ Hot bulb ” engines, 24
- — — *v.* gas mixture, 34
- Hydroplanes, 62
- INLAND water transport, tug for, 80
- Internal combustion engine, definition of, 1
- — —, action of, 10
- — —, history of, 3
- LIGHTNESS and reliability, 58
- MANUFACTURING, methods of, 109
- Marine motors, difference from car motors, 4
- “ M.L.’s,” 9
- Motor boats, advantages of, 37
- — —, definition of, 1
- — — warships, possibilities of, 112
- NAVAL motor boats, fuel for, 54
- OPPOSED piston engine, Doxford, 97
- “ Otto ” cycle, 11

- PARAFFIN, properties and use of, 48
 Petrol, properties and use of, 46
 Petroleum, general characteristics of, 45
 "Petter" engines, 88
 Pistons, cooling of, 16, 98
 Power required for large ships, 104
 Pre-ignition, 25
 Producer gas, 50

 RACE, Calais to Dover, 4
 Racing motor boats, speed of, 5
 Ramus, suggestion for skimming boat, 63
 Reliability and lightness, 58
 Reversing, 28
 Revolutions of different types of engine, 59
 Rudder motor, Evinrude, 70

 SAILING boats, auxiliary motors for, 41
 — ship, auxiliary, with Petter engine, 95
 Skimming boats, 62
 Starter, electric, 86

 Starting of engines, 28
 — of Vickers-Petter engine, 92
 Steam engines, weight of, 38
 — —, fuel consumption of, 39
 "Sterling" engines, 82
 Submarines, 8
 —, fuel for, 55

 "THORNYCROFT" motors, 73
 Torpedo boats, 73
 — — machinery, weight of, 39
 "Two-stroke" cycle, 20
 — — v. four-stroke, 32
 — — engine, cheapness of, 33

 U.S.A., development of motor boats in, 6

 "VICKERS-PETTER" motors, 88

 WAR, motor boat in, 8
 Weight and engine speed, 56
 Weights of different engines, 4, 38

 "YNGAREN" motor ship, 100

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